

# **Concentrations of Ultrafine Particles and Related Air Pollutants On and Near Roadways and in Other Urban Microenvironments**

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Bay Area Air Quality Management District  
Advisory Council Meeting  
San Francisco  
February 8, 2012

- Combustion source characterization – rates and composition of emissions.
  - Fine and ultrafine particles - organic compounds, elemental carbon (soot), metals
  - Volatile and semi-volatile organic compounds
  - CO, NO<sub>2</sub>
- Pollutant concentrations in urban microenvironments (ME).



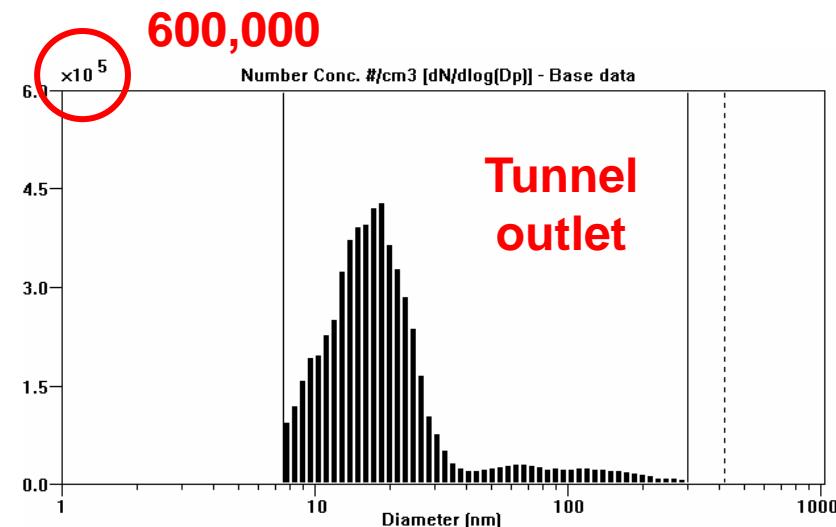
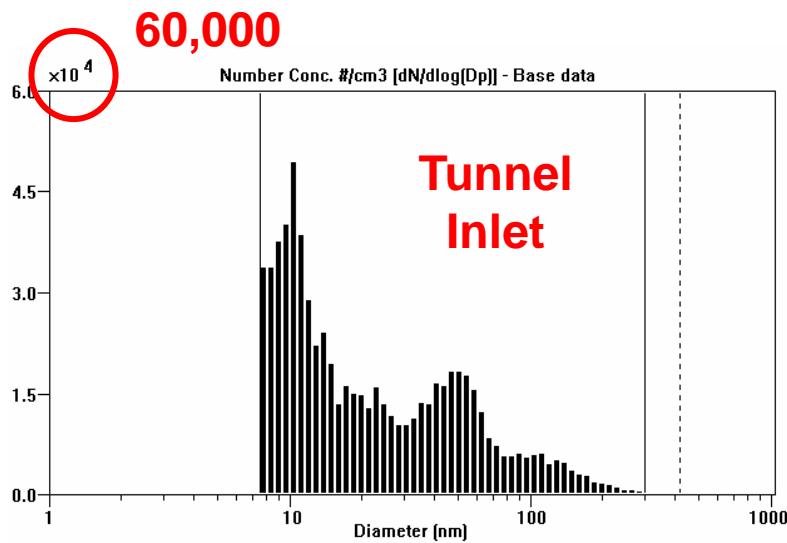
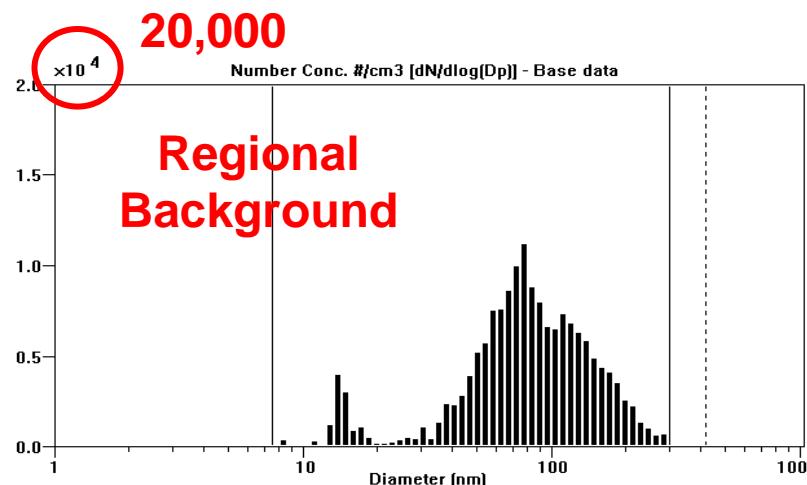
# Emission Characterization Studies

- **Gasoline/Diesel PM Split Study (DOE NREL)**
  - Fujita, E.M., B. Zielinska, D.E. Campbell, W.P. Arnott, J. Sagebiel, L. Reinhart, J.C. Chow, N. P.A. Gabele, W. Crews, R. Snow, N. Clark, S. Wayne and D.R. Lawson (2007). Variations in speciated emissions from spark-ignition and compression ignition motor vehicles in the California's South Coast Air Basin. *J. Air & Waste Manage. Assoc.* 57:705-720.
  - Fujita, E. M., D. E. Campbell, W. P. Arnott, B. Zielinska (2007). Evaluations Of Source Apportionment Methods for Determining Contributions Of Gasoline and Diesel Exhaust to Ambient Carbonaceous Aerosols. *J. Air & Waste Manage. Assoc.* 57:721-740.
- **Kansas City Vehicle Characterization Study (USEPA, FHA, DOE NREL, CRC)**
  - Fulper, C.R., S. Kishan, R.W. Baldauf, M. Sabisch, J. Warila, E.M. Fujita, C. Scarbro1 W.C. Crews, R. Snow, P. Gabele, R. Santos, G. Tierney, and B. Cantrell (2010). Methods of Characterizing the Distribution of Exhaust Emissions from Light-Duty, Gasoline-Powered Motor Vehicles in the U.S. Fleet. *J. Air & Waste Manage. Assoc.*
  - Fujita, E.M., D.E. Campbell, B. Zielinska (2006). Chemical Analysis of Lubrication Oil Samples from a Study to Characterize Exhaust Emissions from Light-Duty Gasoline Vehicles in the Kansas City Metropolitan Area. Final report submitted to the National Renewable Energy Laboratory, NREL Contract No. ACI-5-55528-01, Golden, CO, and the Coordinating Research Council, CRC E-69A, Alpharetta, GA, December 31, 2006.
- **Advanced Collaborative Emission Study (HEI, CRC, DOE NREL)**
  - Khalek, I.A., T. Bouger, P. Merritt and B.Zielinska (2011): Regulated and Unregulated Emissions from Highway HDD Engines Complying with U.S. EPA 2007 Emissions Standards, *JAWMA* 61: 427-442
- **Collaborative Lubricating Oil Study of Emissions (NREL, CRC, SCAQMD, CARB, ACC)**
  - Carroll, J.N., Khalek, I.A., Smith, L.R., Fujita, E.M., Zielinska, B. (2011). Collaborative Lubricating Oil Study on Emissions (CLOSE). Final report submitted to National Renewable Energy Laboratory (AEV-7-66409-1) and Coordinating Research Council (AVFL-14), August 2011.
- **EPAct (Energy Policy Act of 2005 Comprehensive Gasoline Light Duty Exhaust Fuel Effects) Test Program (USEPA, DOE NREL, CRC)**
  - In Progress.

# Exposure Assessment Studies

- Section 211(B) Tier 2 High End Exposures (API)
  - Zielinka, B., E.M. Fujita, J.C. Sagebiel, and D.E. Campbell (2006). Section 211(B) Tier 2 High End Exposure Study of Conventional and Oxygenated Gasoline. Final Report submitted to the American Petroleum Institute, Washington, D.C., July 19, 2006.
- Assessing Exposure to Air Toxics in Microenvironments Dominated by Mobile Sources (HEI)
  - Fujita, E.M., D.E. Campbell, B. Zielinska, W.P. Arnott and J.C. Chow (2007). Exposure to Air Toxics in Mobile Source Dominated Microenvironments. Draft report submitted by Desert Research Institute to the Health Effects Institute, Boston, MA, February 6, 2007.
- Roseville Railyard (PCAPCD)
  - Campbell, D.E. and E.M Fujita (2006). Data Analysis on the Roseville Rail Yard Air Monitoring Project. Final report submitted to the Placer County Air Pollution Control District, Auburn, CA, March 15, 2006.
- Harbor Community Monitoring Study (CARB)
  - Fujita, E.M., D.E. Campbell, B. Mason, B. Zielinska (2009). Harbor Community Monitoring Study (HCMS) Saturation Monitoring. Final report submitted to the California Air Resources Board, Sacramento CA, May 15, 2009.
- West Oakland Monitoring Study (BAAQMD)
  - Fujita, E.M. and D.E. Campbell (2010). West Oakland Monitoring Study. Final report prepared for the Bay Area Air Quality Management District, San Francisco, CA, October 7, 2010.
- Exposure Classification Project (API)
  - In Progress
- LAX Air Quality Source Apportionment Study (LAWA)
  - In Progress.

# Particle Number Concentration Distribution at the Tuscarora Tunnel, 5/21/99

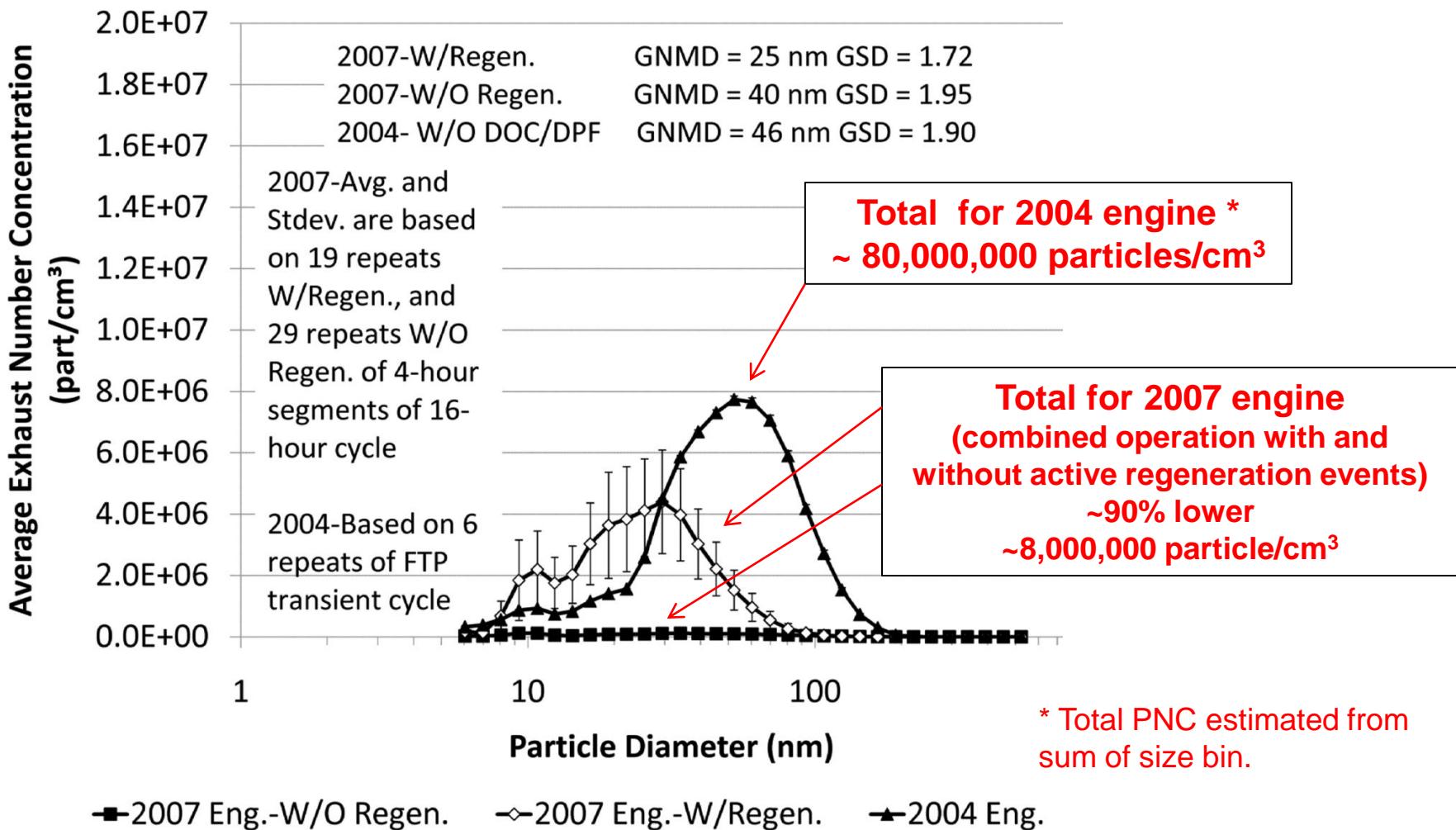


Total ~ 6,000,000 particle/cm<sup>3</sup>

\* Source: HEI Project 98-3 courtesy of Dr. Fred Rogers, Desert Research Institute.

# Size Distributions of Exhaust Particles

2004 diesel engine versus 2007 with and without C-DPF active regeneration



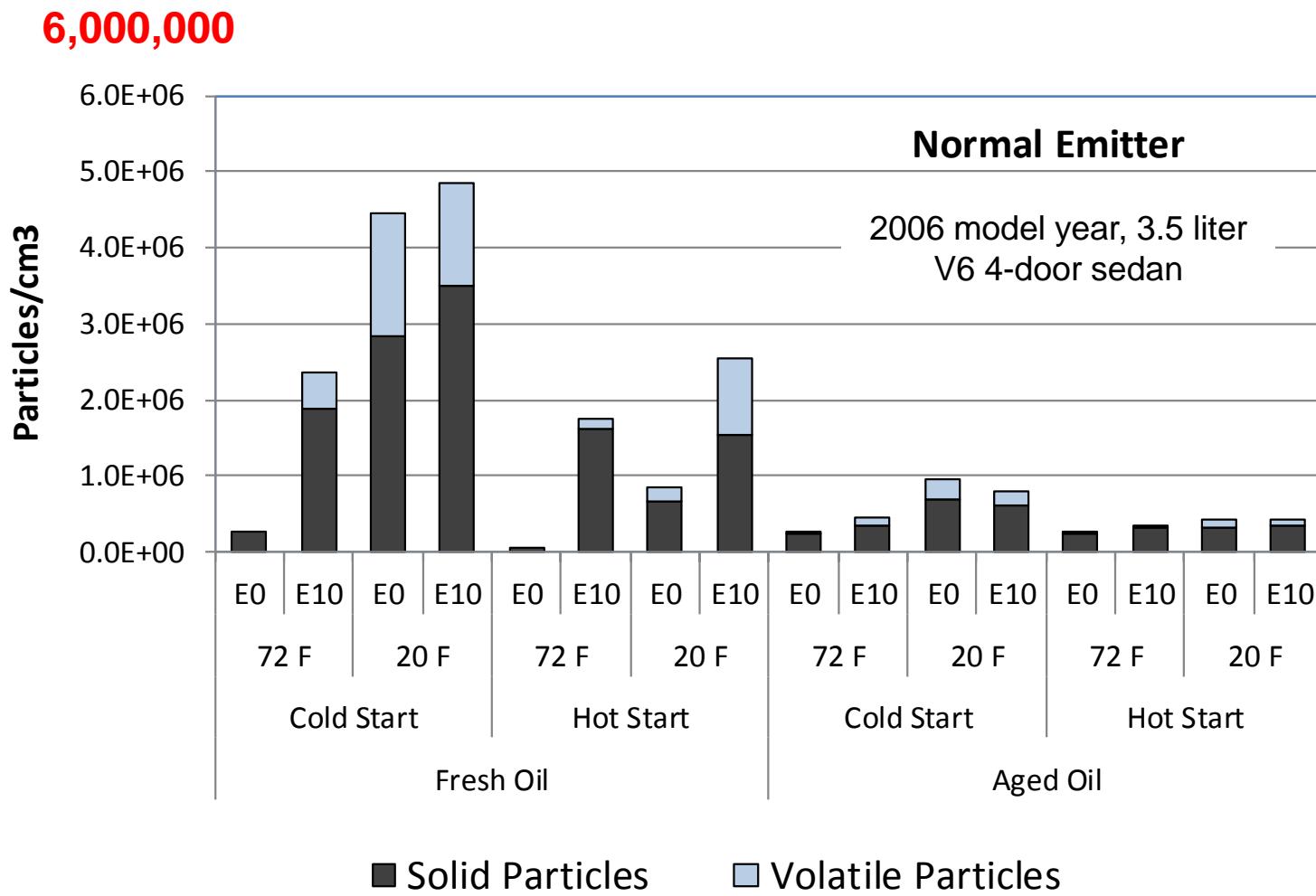
## ACES

Khalek, I.A., T. Boughey, P. Merritt and B. Zielinska (2011): Regulated and Unregulated Emissions from Highway HDD Engines Complying with U.S. EPA 2007 Emissions Standards, JAWMA 61: 427-442

# Comparison of Unregulated Emissions of 2007 ACES Engines with 2004 Engines

	2004 Engines	2007 Engines	Avg. % Reduction Relative to 2004 Engines
	Avg, mg/hr	Avg, mg/hr	
Single Ring Aromatics	405.0	71.6	82%
PAH	325.0	69.7	79%
Alkanes	1030.0	154.5	85%
Hopanes/Steranes	8.2	0.1	99%
Alcohols and Organic Acids	555.0	107.4	81%
Nitro-PAH	0.3	0.1	81%
Carbonyls	12500.0	255.3	98%
Inorganic Ions	320.0	92.3	71%
Metals and Elements	400.0	6.7	98%
OC	1180.0	52.8	96%
EC	3445.0	22.6	99%

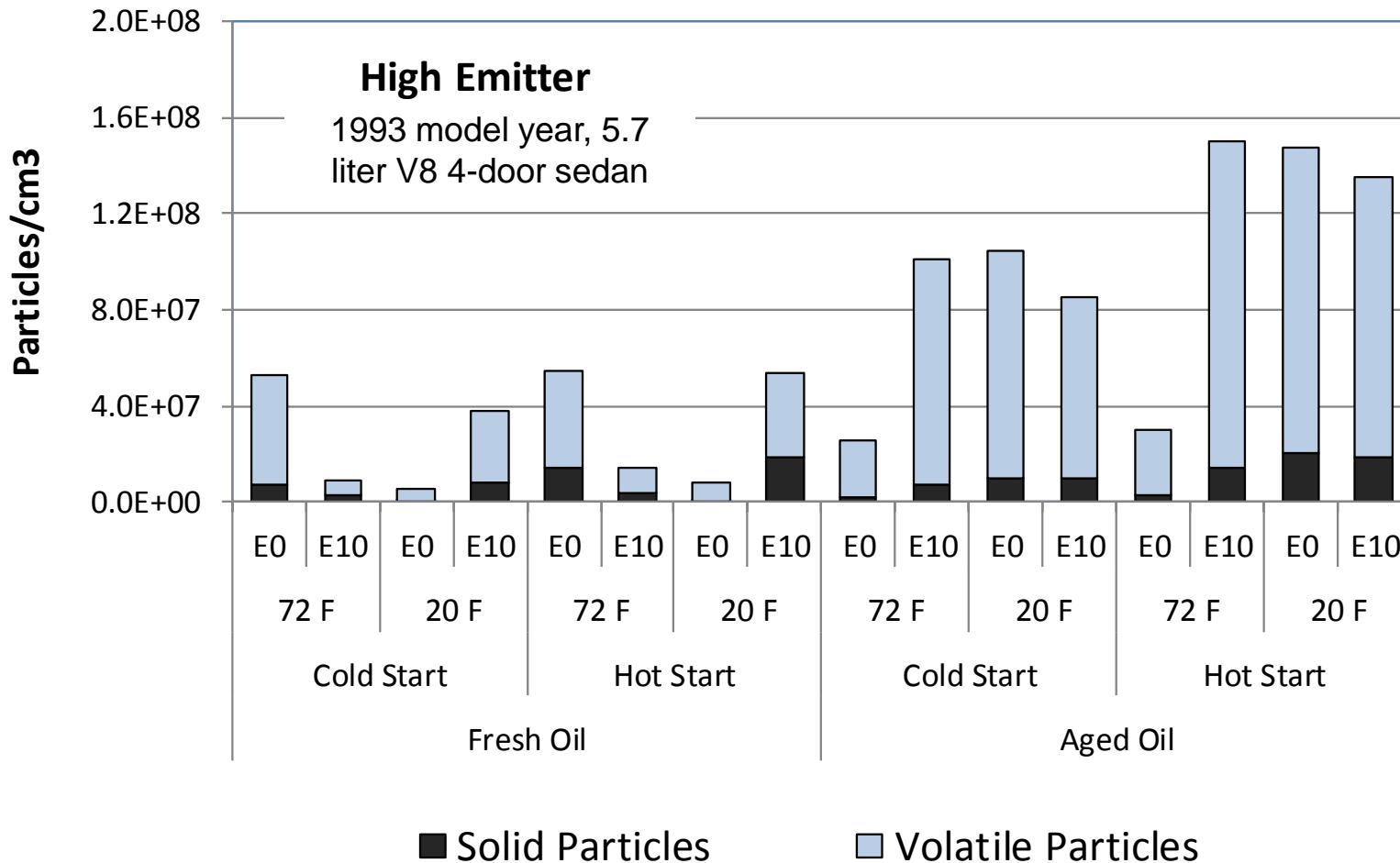
# Exhaust PNC (particles/cm<sup>3</sup>) of Solid and Volatile Particles Normal Emitting LDGV



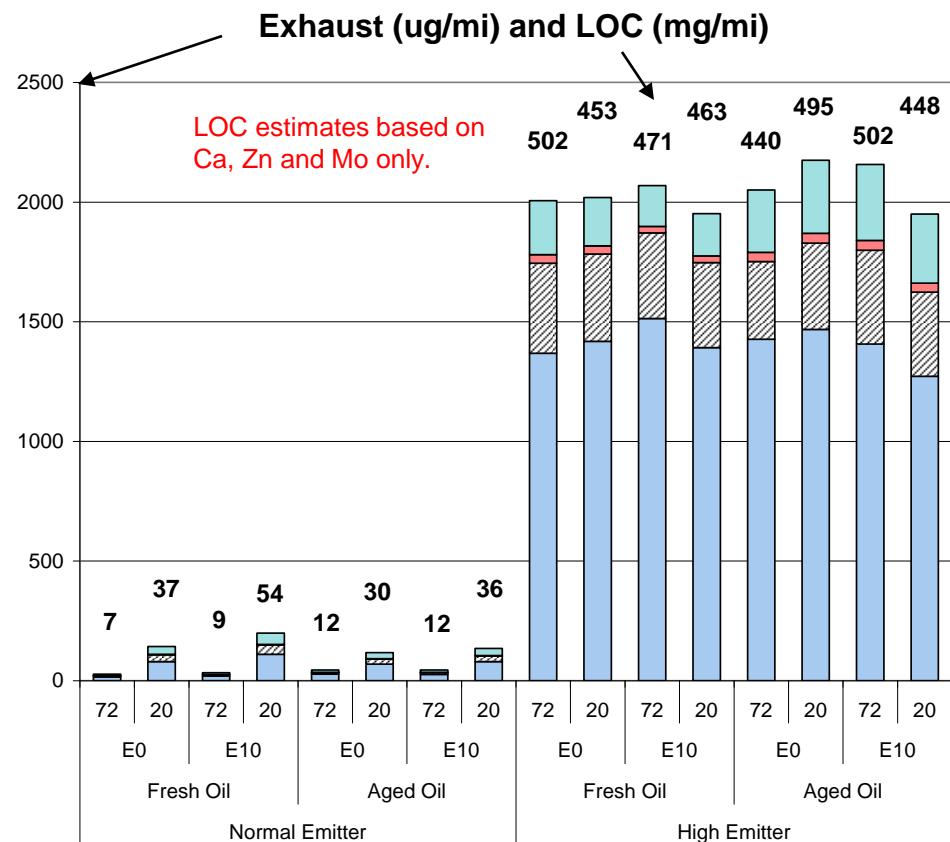
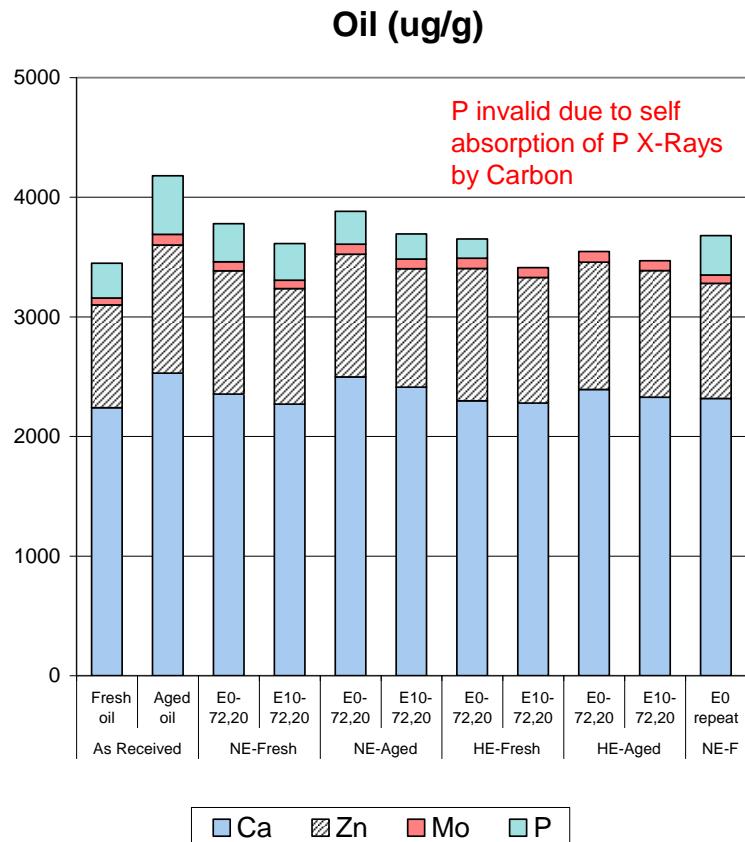
PNC generally higher with fresh oil and lower temperature (20 °F).  
Mostly solid particles

# Exhaust Particle Number Concentrations (particles/cm<sup>3</sup>) of Solid and Volatile Particles - CLOSE Project

200,000,000



# Exhaust Emissions Rates of Ca, Zn, Mo and P, Mass Fractions in Lubricating Oils and Estimated LOC



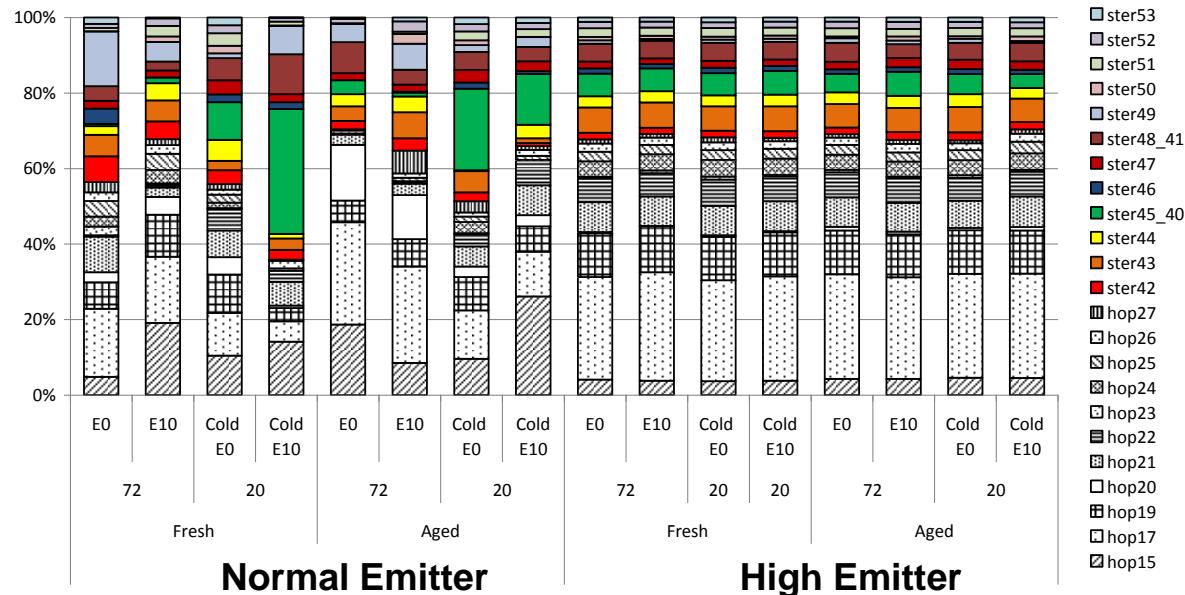
$$LOC_{estimated}(g / mi) = \frac{T_{Exh}(\mu g / mi)}{T_{Oil}(\mu g / g)} = A * LOC_{actual}$$

Legend: Ca (blue), Zn (grey), Mo (red), P (teal), LOC

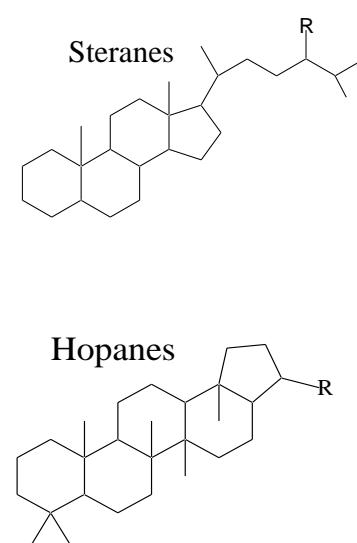
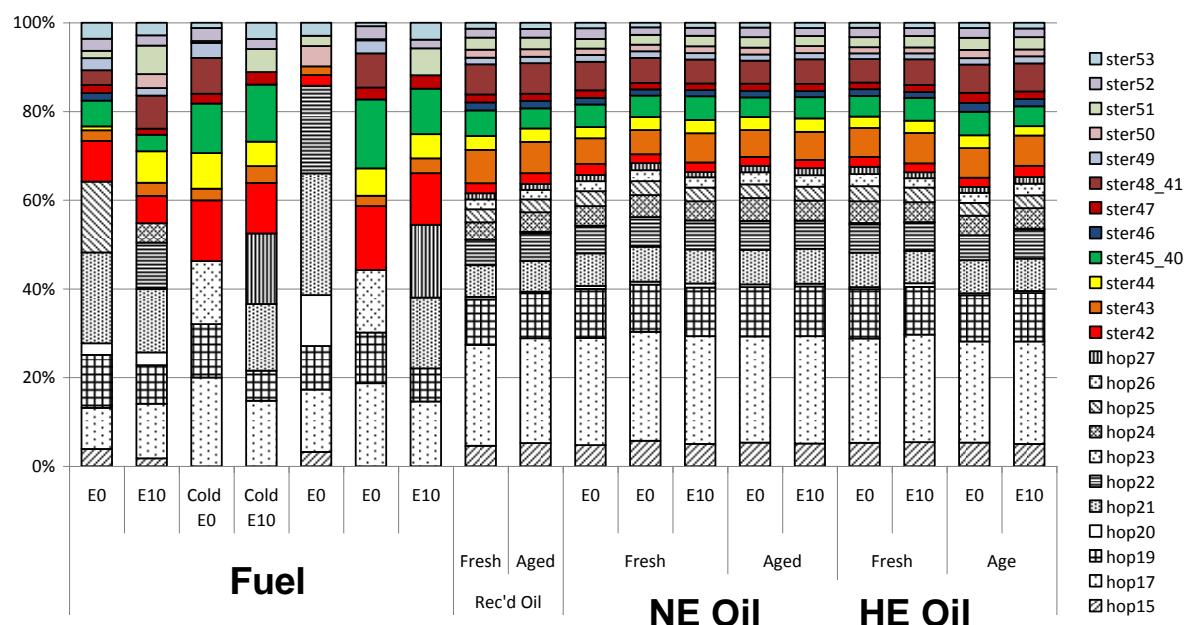
LOC<sub>est</sub> for HE > mean TC for HE of 67 mg/mi.

# Hopanes and Steranes

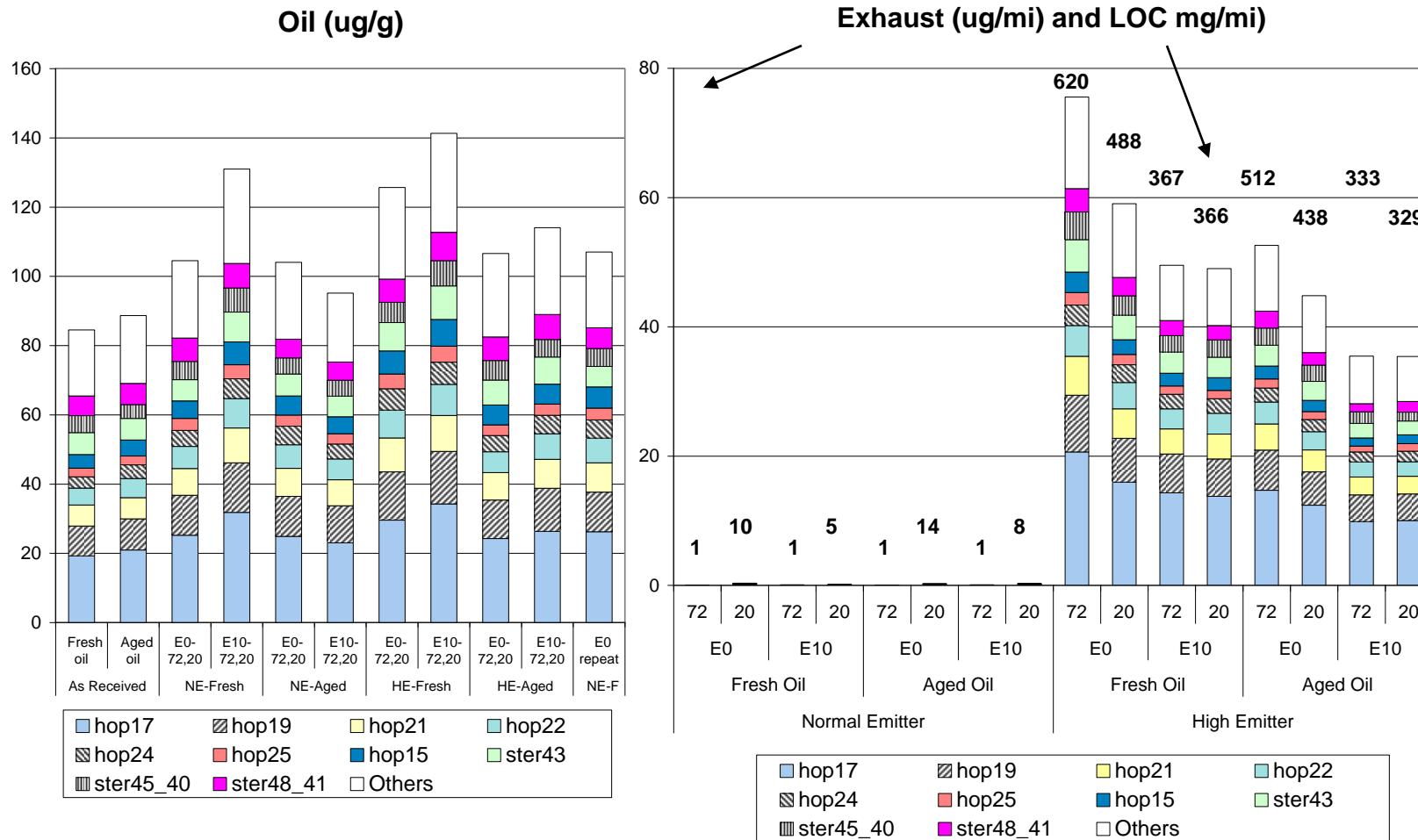
Exhaust  
PM



Fuel and  
Oils

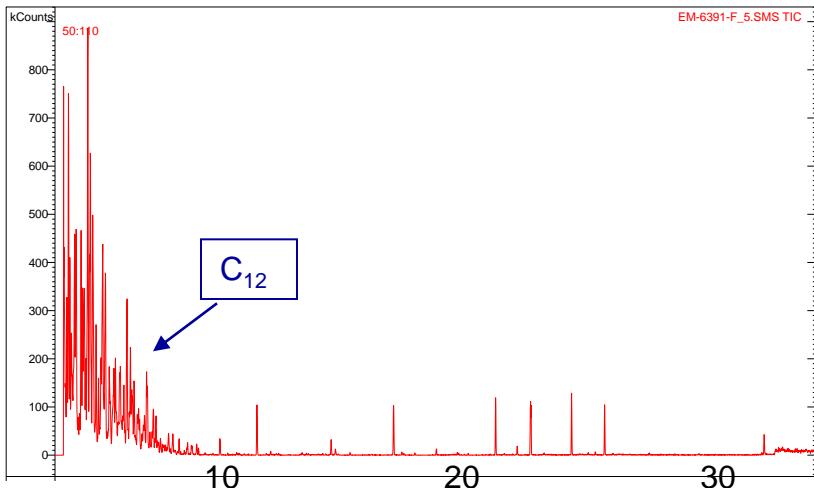


# Exhaust Emission Rates of Hopanes & Steranes, Mass Fractions in Lubricating Oils and Estimated LOC

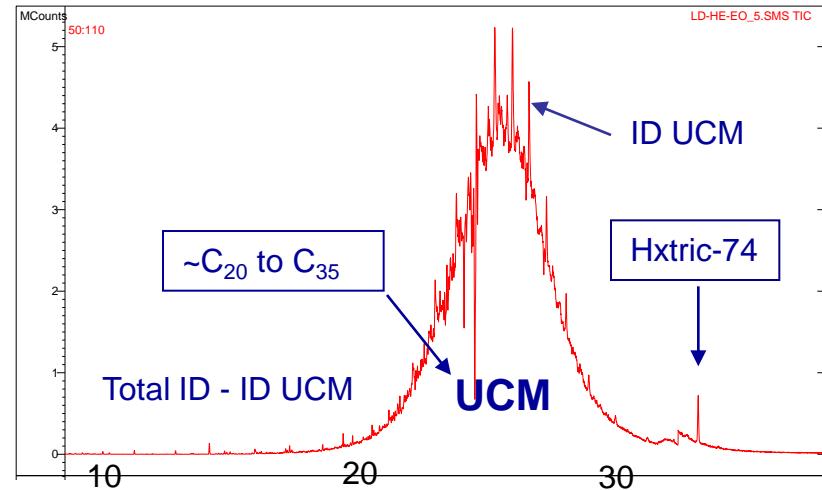


# GC-MS Chromatograms of Alkanes for Fuel, Oil, and NE and HE Exhaust

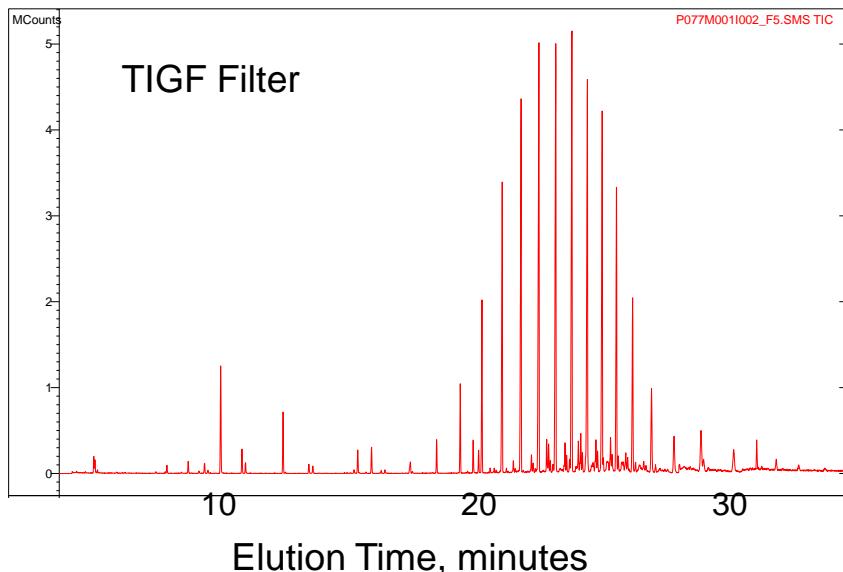
## Gasoline



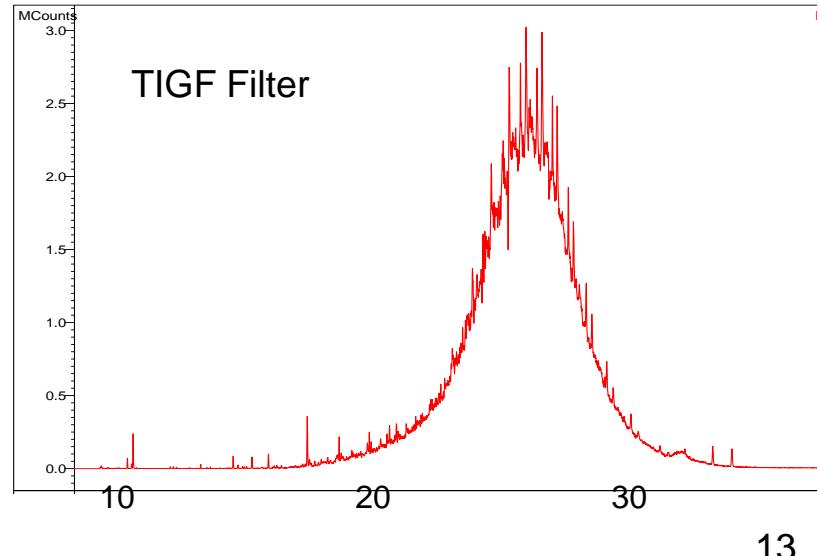
## Lubricating Oil



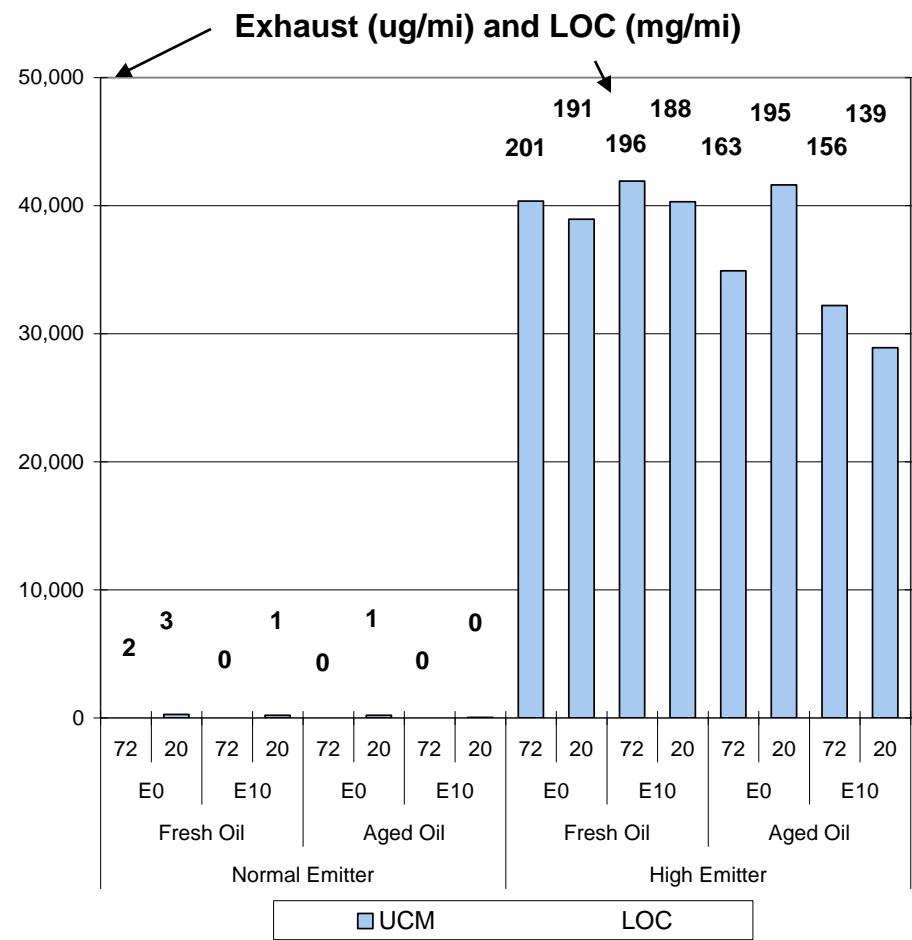
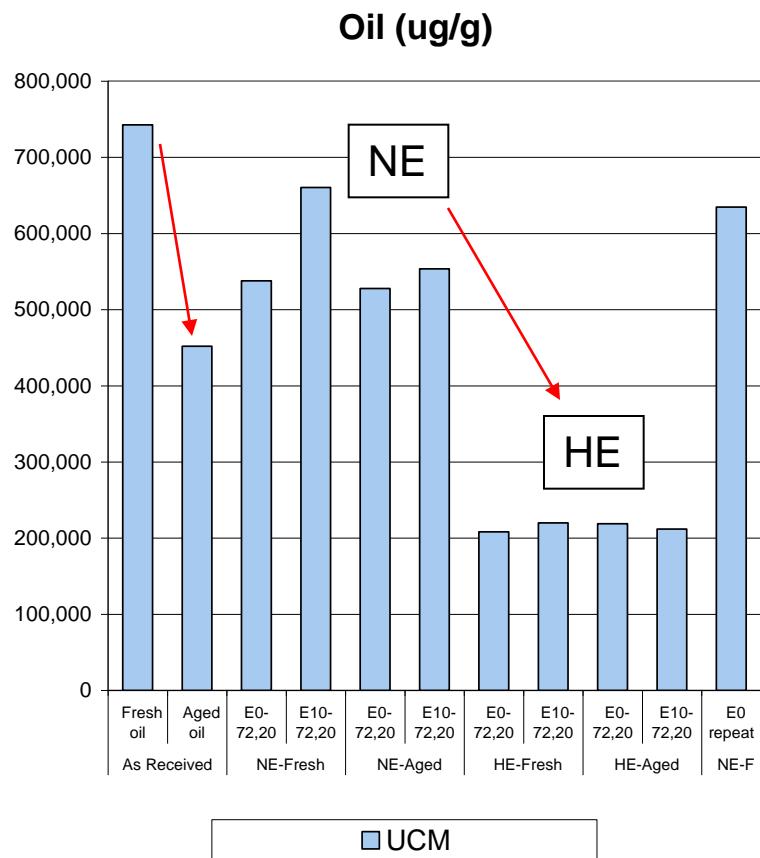
## Normal Emitter Exhaust



## High Emitter Exhaust



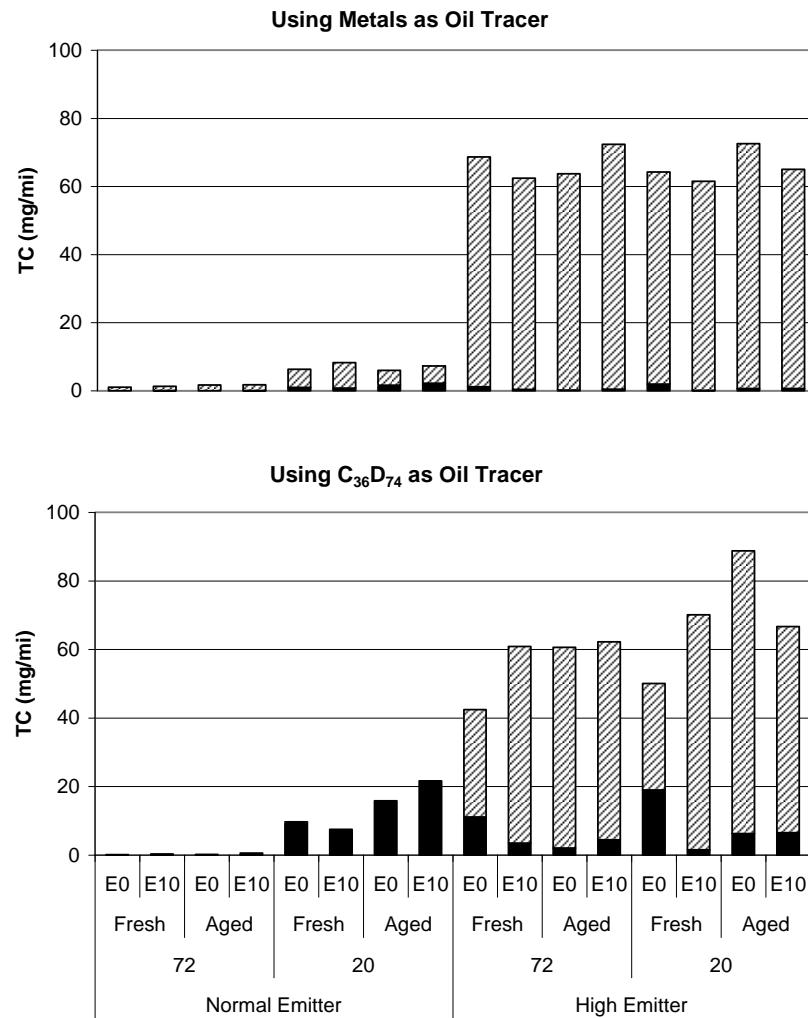
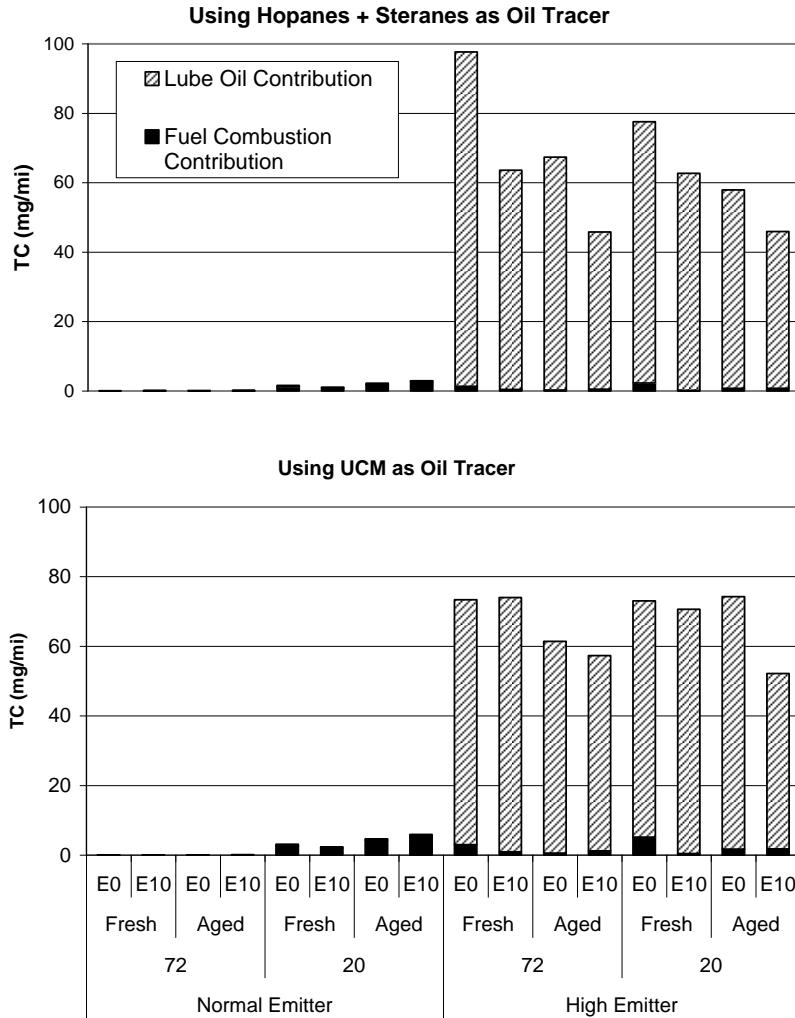
# Exhaust Emission Rates of UCM, Mass Fractions in Lubricating Oils and Estimated LOC



$UCM_{fresh} > UCM_{aged}$  and  $UCM_{NE} > UCM_{HE}$

Due to oxidation of alkanes???

# MLR Estimates of Lubricating Oil and Fuel Combustion Contributions (mg/mi) to Total Carbon – CLOSE Project



# Emission of PM Relative to Lubricating Oil and Fuel Combustion Tracers

ID	PM (mg/mi)	OC (mg/mi)	EC (mg/mi)	TC (mg/mi)	EC/TC	Elem ( $\mu$ g/mi)	H&S ( $\mu$ g/mi)	UCM (mg/mi)	PAH ( $\mu$ g/mi)
S1-2	81.7	26.1	17.9	44.0	0.41	0.06	0.04	0.01	0.37
S2-1	73.1	59.1	4.5	63.6	0.07	1.10	0.19	25.55	0.01
S5-1	18.1	9.0	9.9	19.0	0.52	0.08	0.13	0.00	0.13
S5-4	207.4	101.6	77.6	179.2	0.43	1.02	0.45	39.47	1.03
S5-5	99.6	33.9	50.9	84.8	0.60	0.44	0.20	0.01	0.48
S6-1	41.6	35.6	0.6	36.2	0.02	0.20	0.06	17.40	0.00
S6-2	49.0	9.1	36.6	45.7	0.80	0.21	0.02	0.00	0.35
S6-3	10.1	3.7	4.7	8.5	0.56	0.37	0.01	0.58	0.02
W1-1	113.1	75.0	14.1	89.1	0.16	0.55	0.37	41.98	0.36
W2-1	52.3	25.7	22.8	48.5	0.47	0.11	0.19	21.95	0.32
W2-2	15.3	4.8	3.6	8.4	0.43	0.18	0.02	3.55	0.01
W6-1	56.3	32.1	20.4	52.5	0.39	0.68	0.22	25.37	0.21

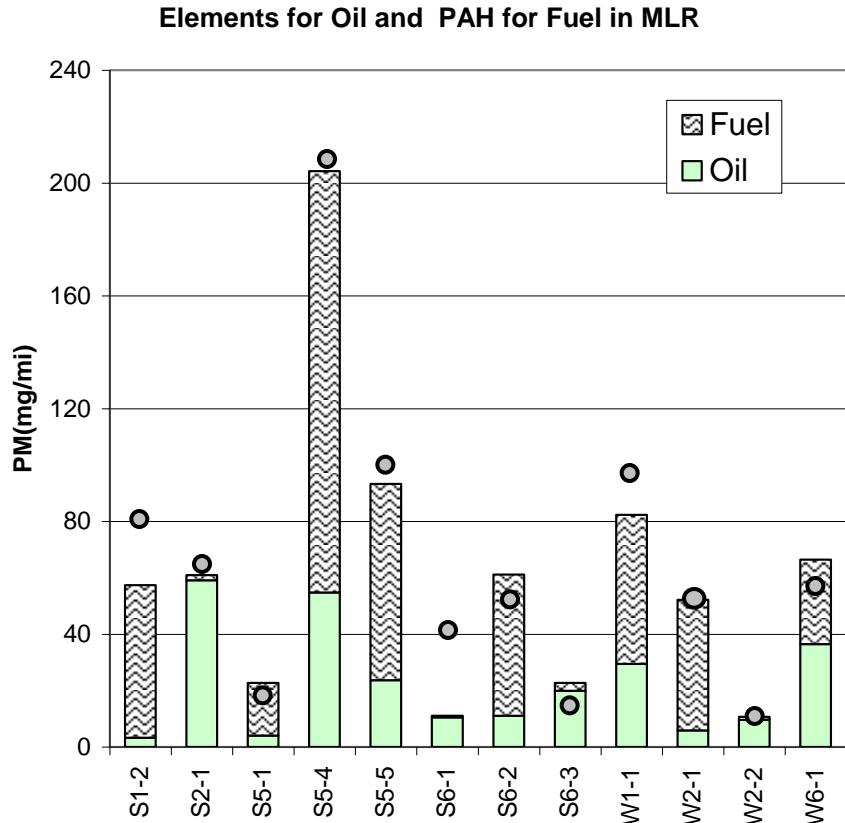
S = Summer, W=winter; Bins 1-4 are trucks and 5-8 are cars.

Bins 1,5 (Pre81), Bins 2,6 (81-90), Bins 3,7 (91-95), Bins 4,8 (96+).

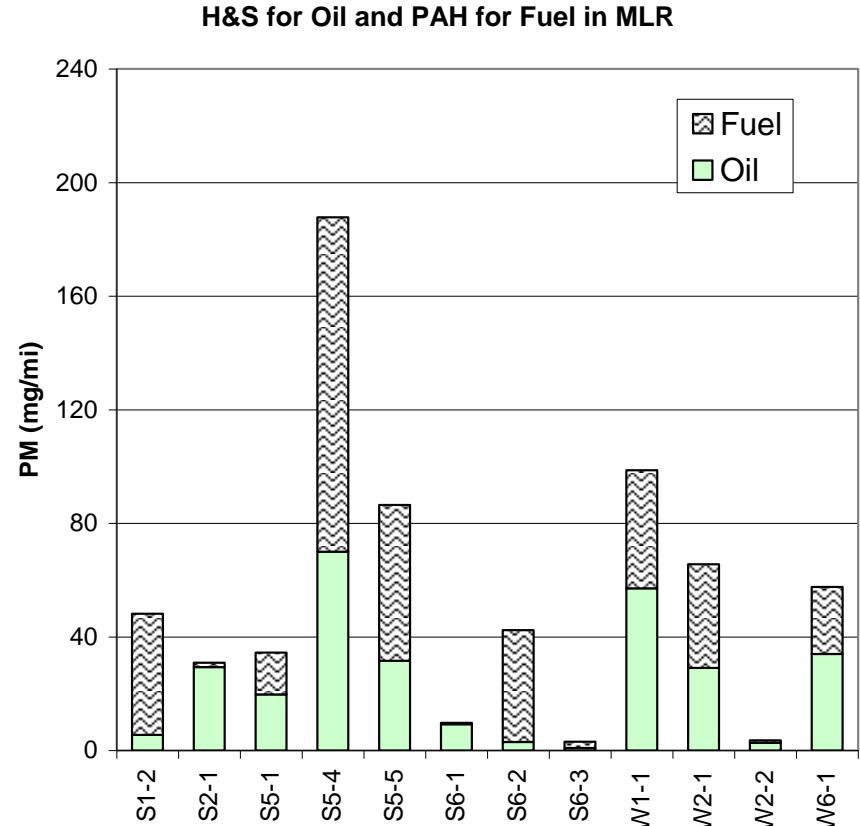
Composites: Bins 1,2,5,6 – single vehicle; Bins 3,7 – up to 3 vehicles; Bins 4,8 – up to 5 vehicles.

Additional analysis of subset of KC Study samples for UCM funded by  
DOE/NREL and LADCO/MARAMA OC Mobile Source Emission Factor Study.

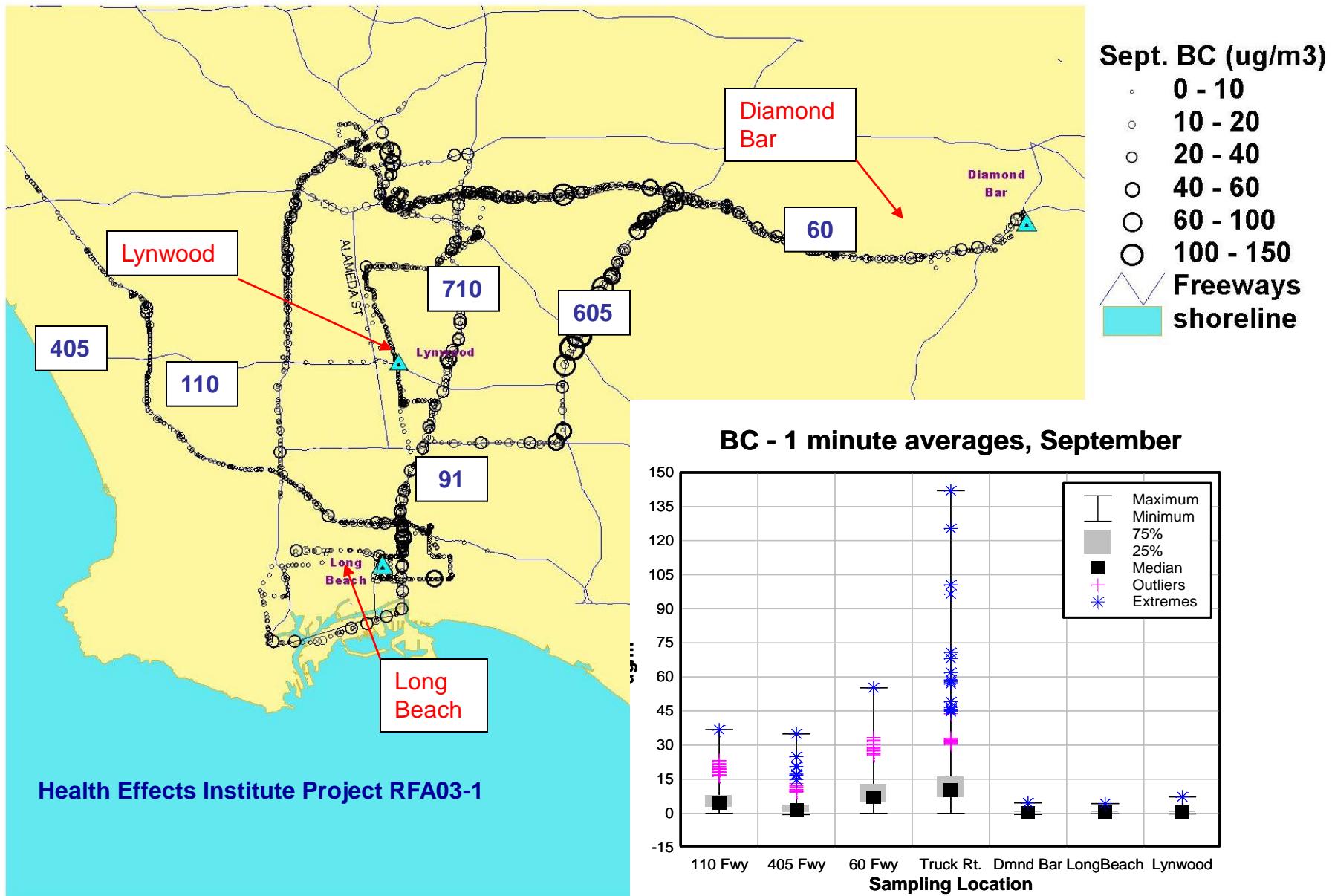
# Fuel and Oil Contributions to PM Emissions by MLR



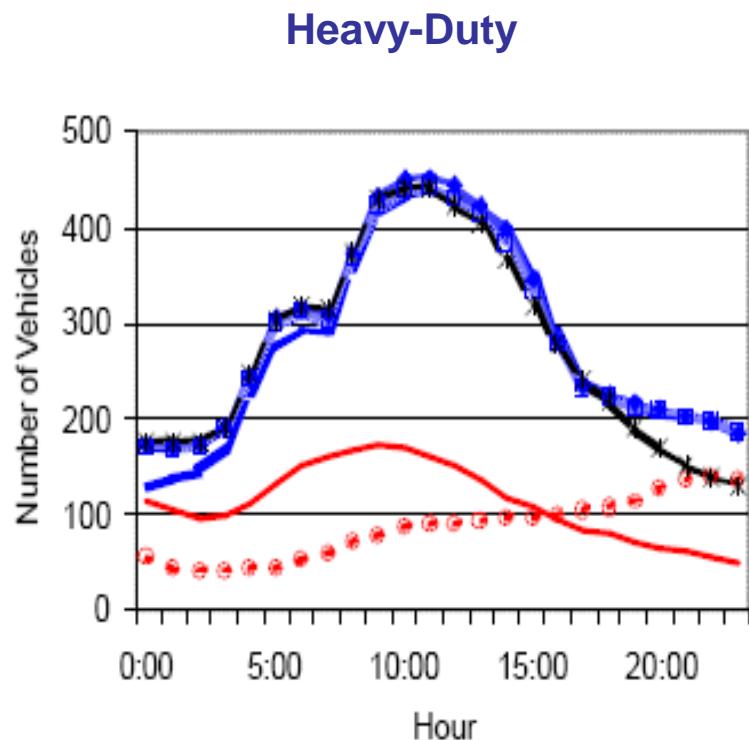
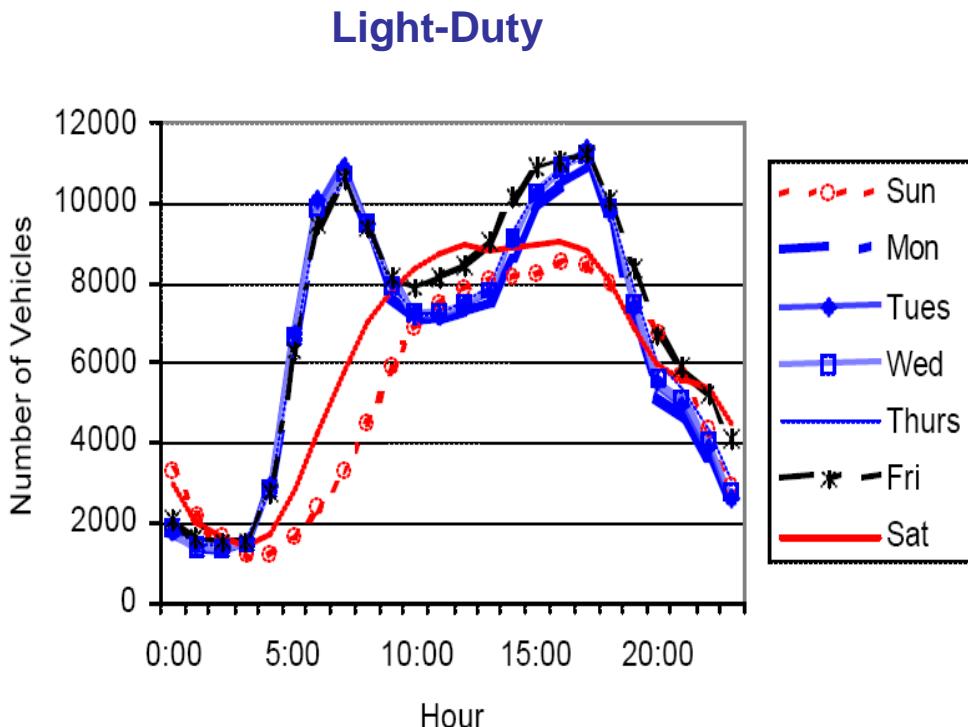
○ Measured PM



# On-Road Black Carbon Concentrations(1-minute)

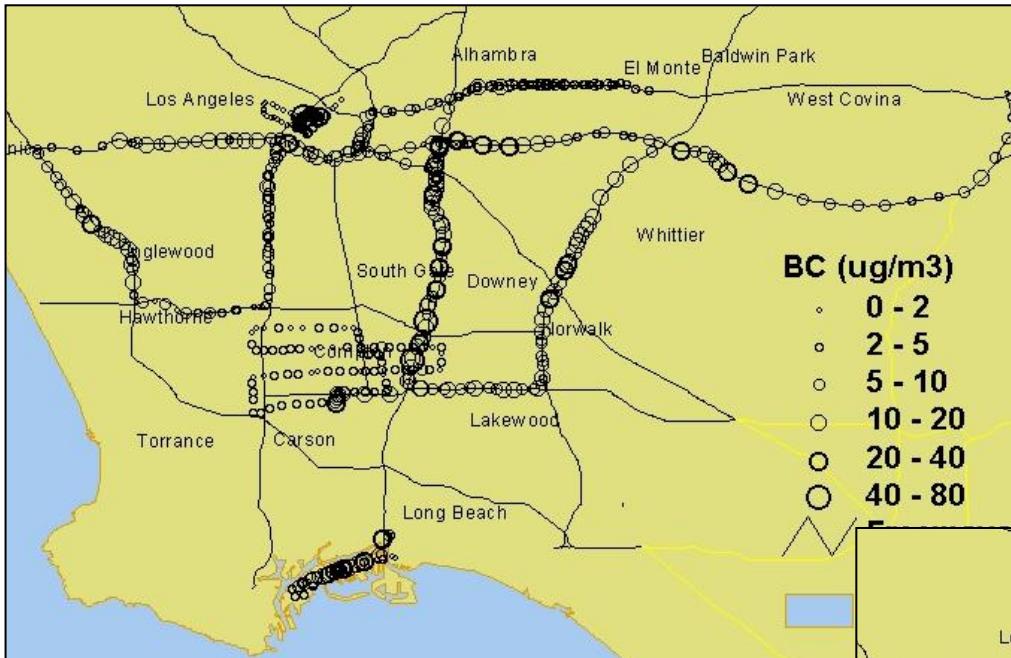


# Average Hourly Light-Duty and Heavy-Duty Traffic Volumes Weigh-in-Motion Sites in Interior of South Coast Air Basin



DOE NREL Weekend Ozone Study  
Courtesy of Sonoma Technology, Inc., 2002

# Black Carbon (1-minute averages)



Sunday

Weekday

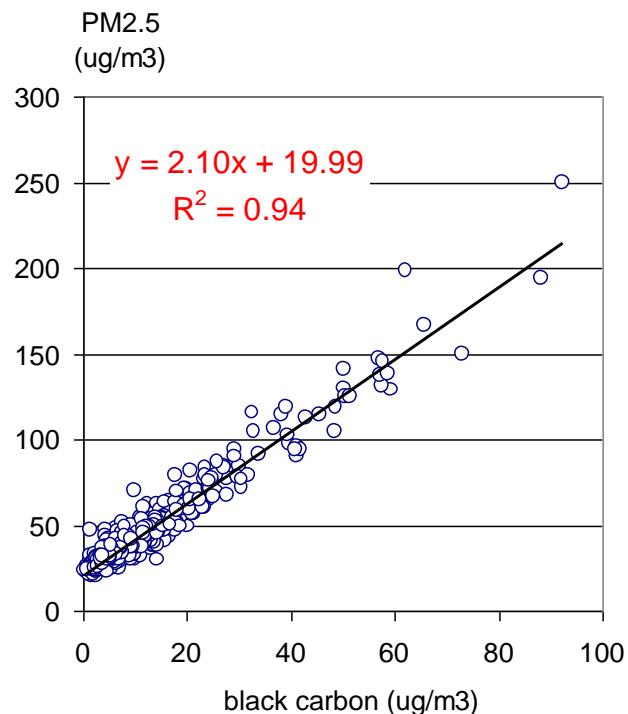
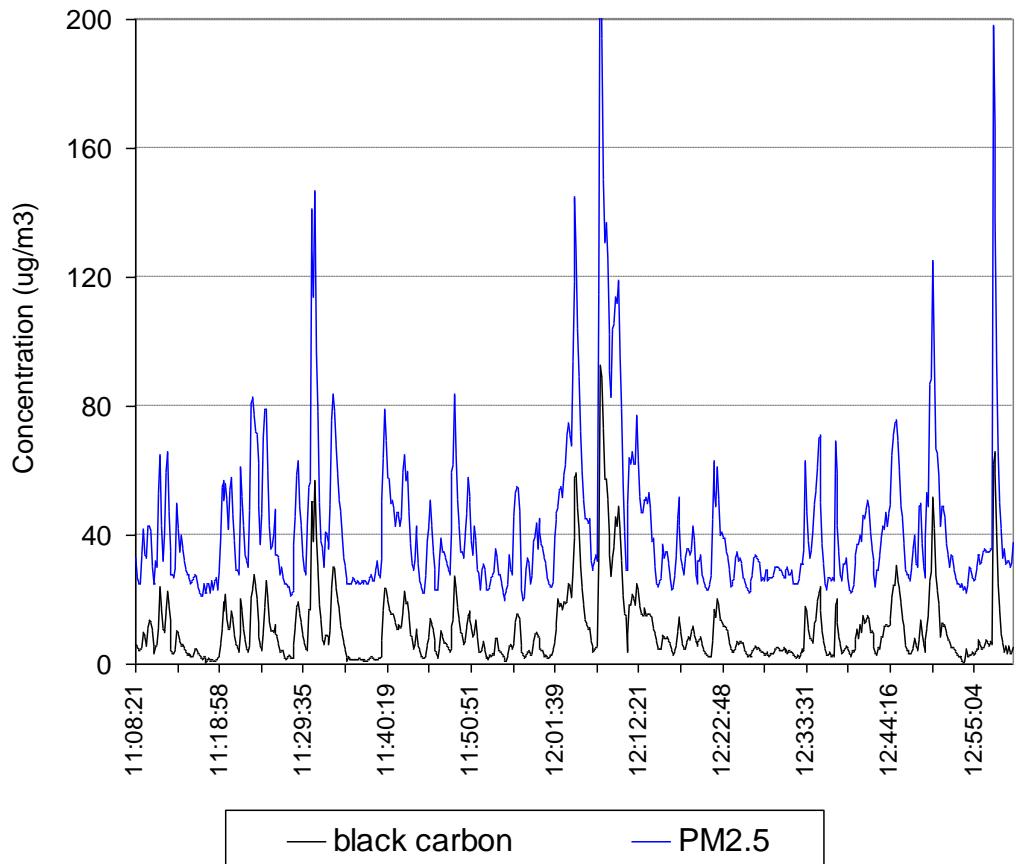


Gasoline/Diesel PM Split Study

# Mobile Sampling – Photoacoustic BC and DustTrak PM<sub>2.5</sub>

## Terminal Island – Port Area

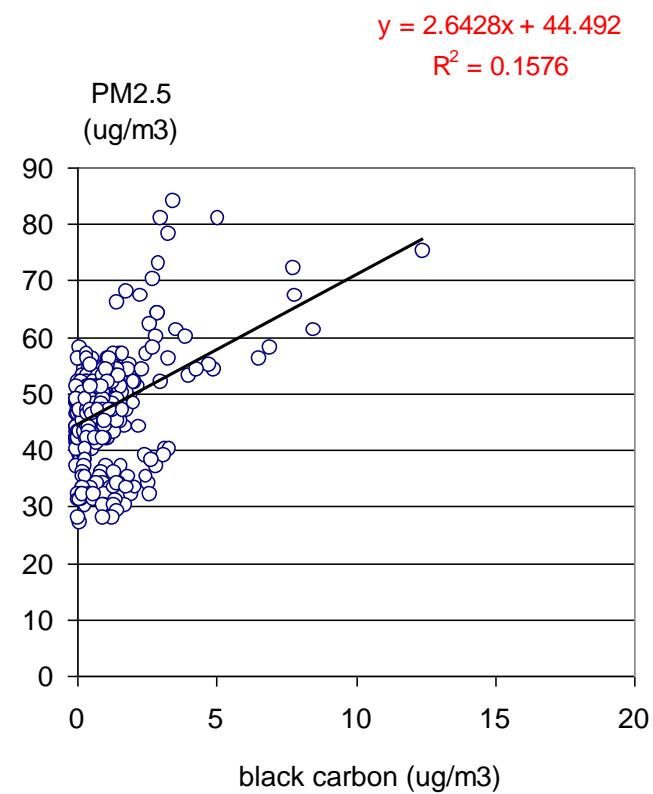
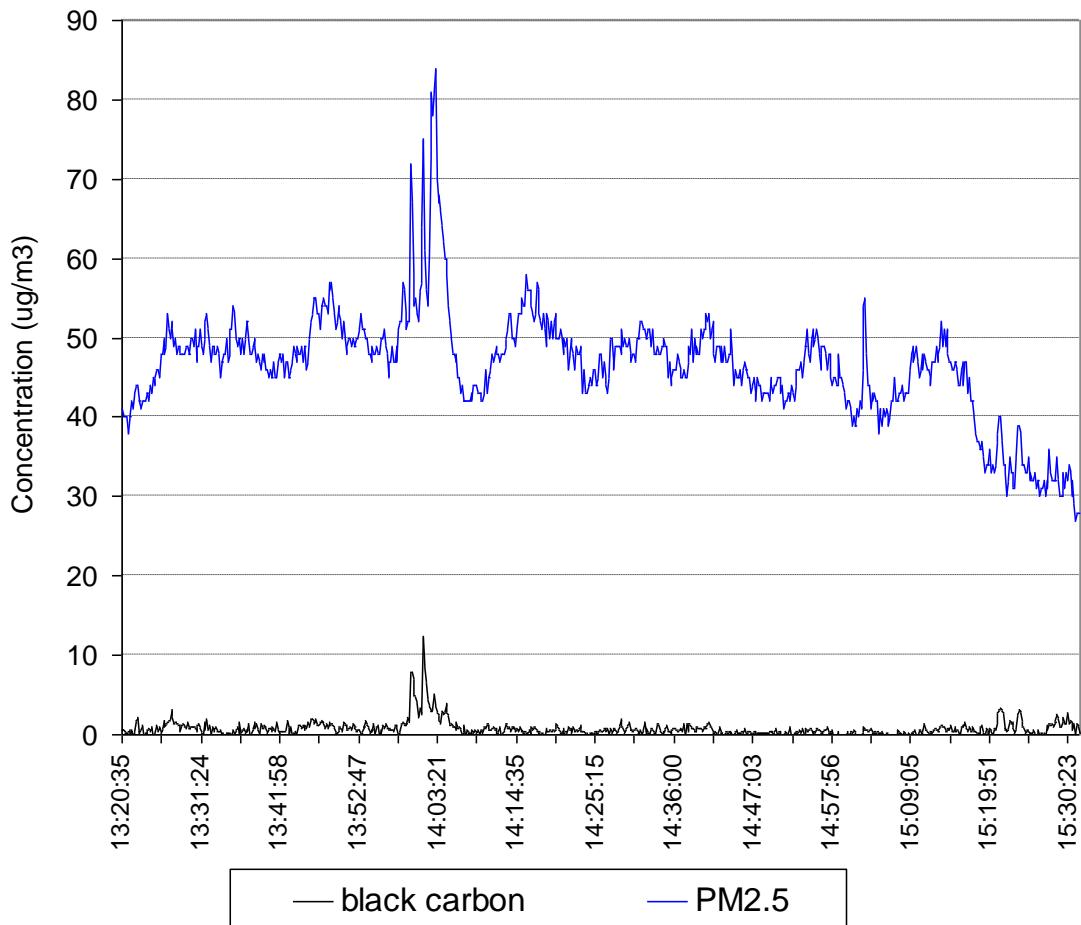
Terminal Island, Tuesday 7/10/01 1105-1300



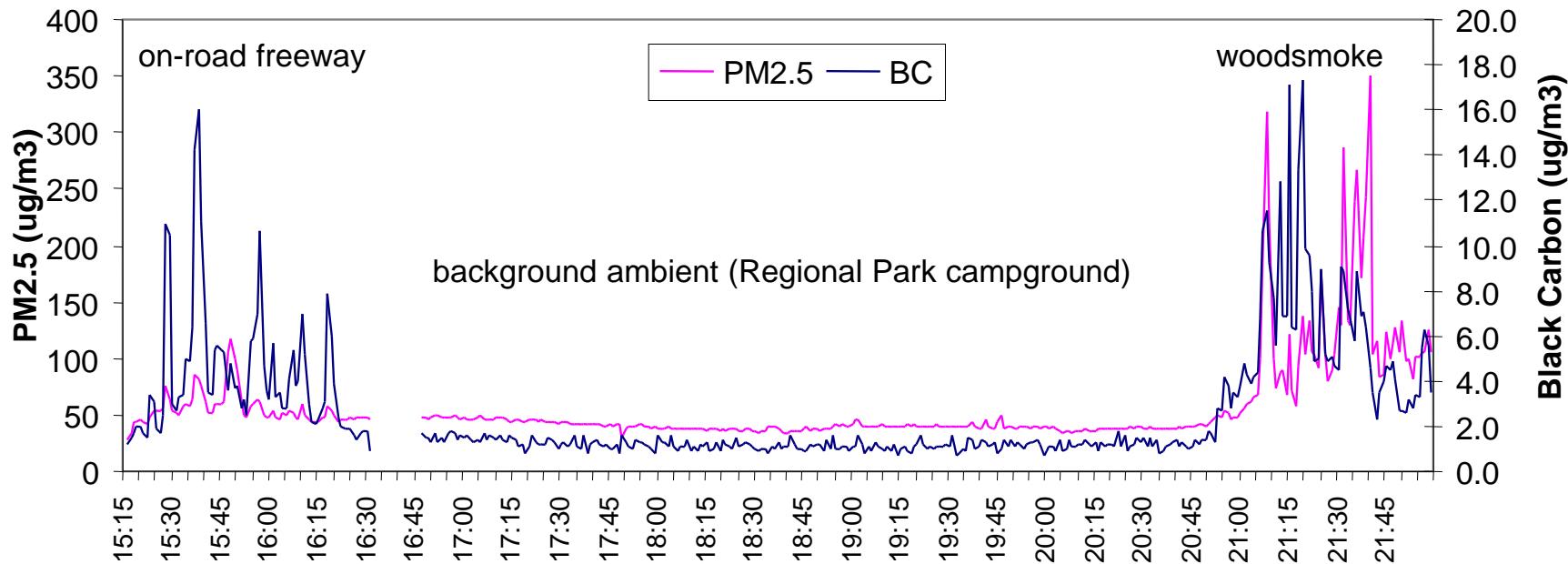
# Gas Diesel PM Split Study

## Mobile Sampling – Photoacoustic BC and DustTrak PM<sub>2.5</sub>

Freeway Hill- SI Under Load, Sun 7/15/01 1316-1532

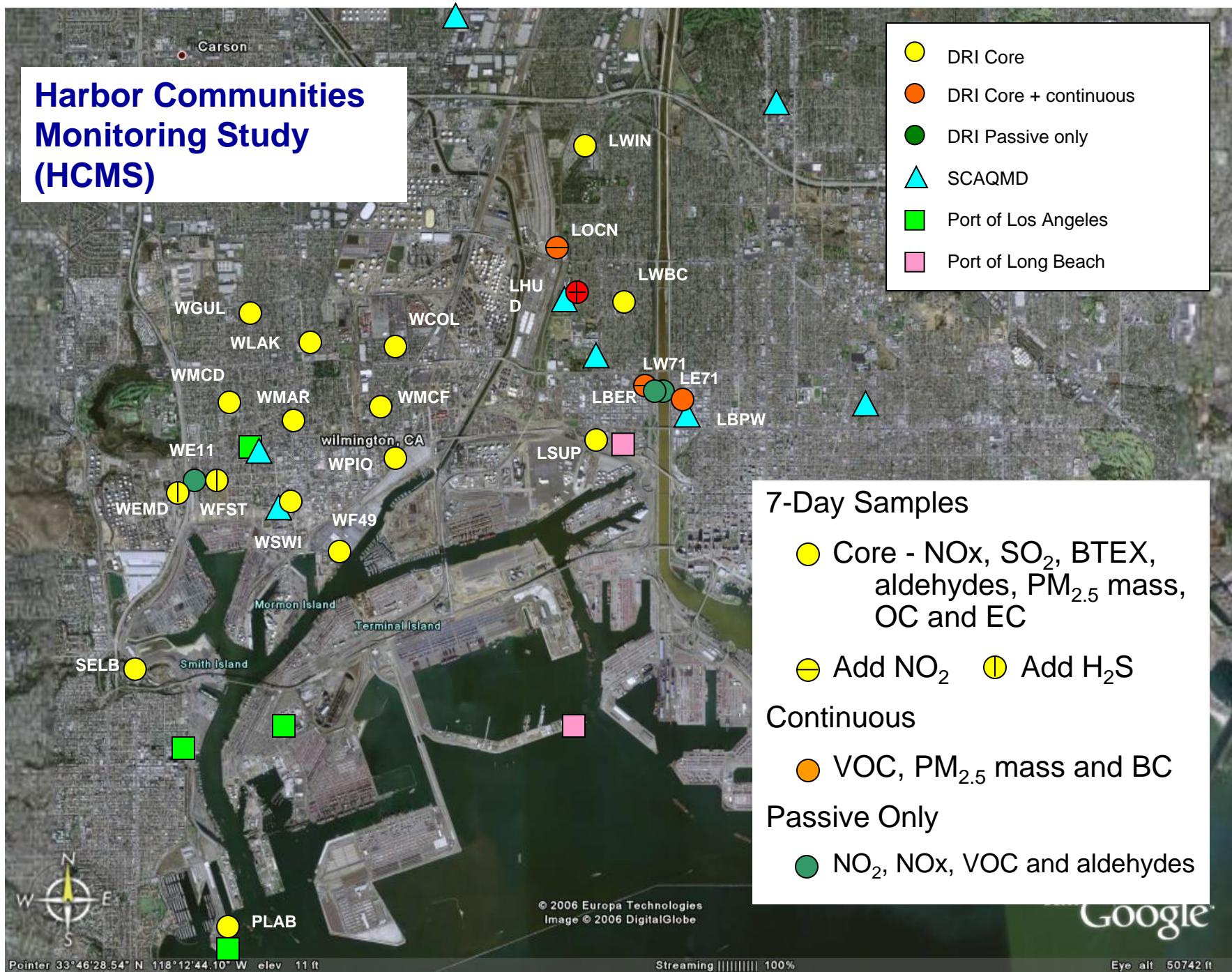


## Mobile PM Measurements - Mixed Sources

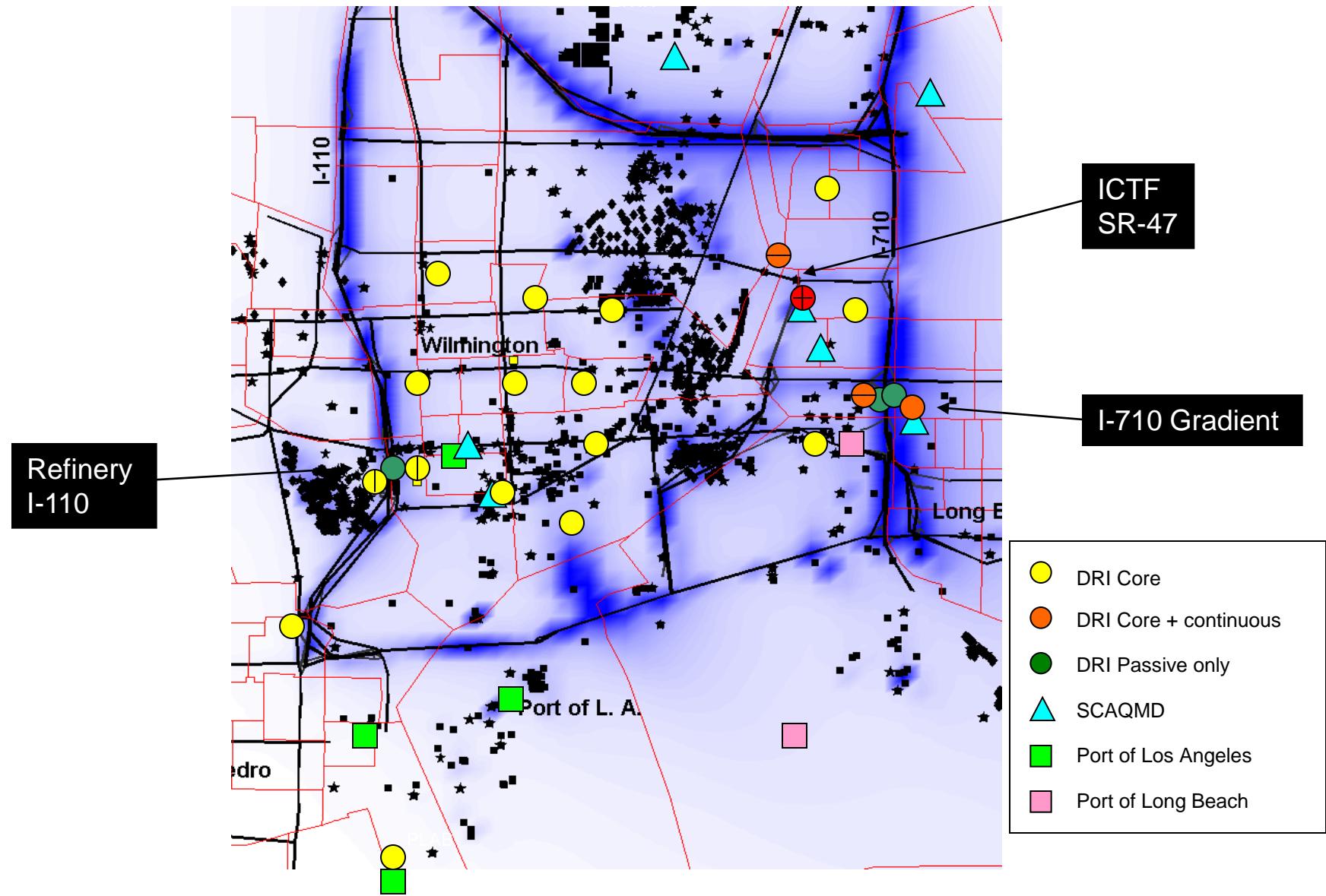


Gasoline/Diesel PM Split Study

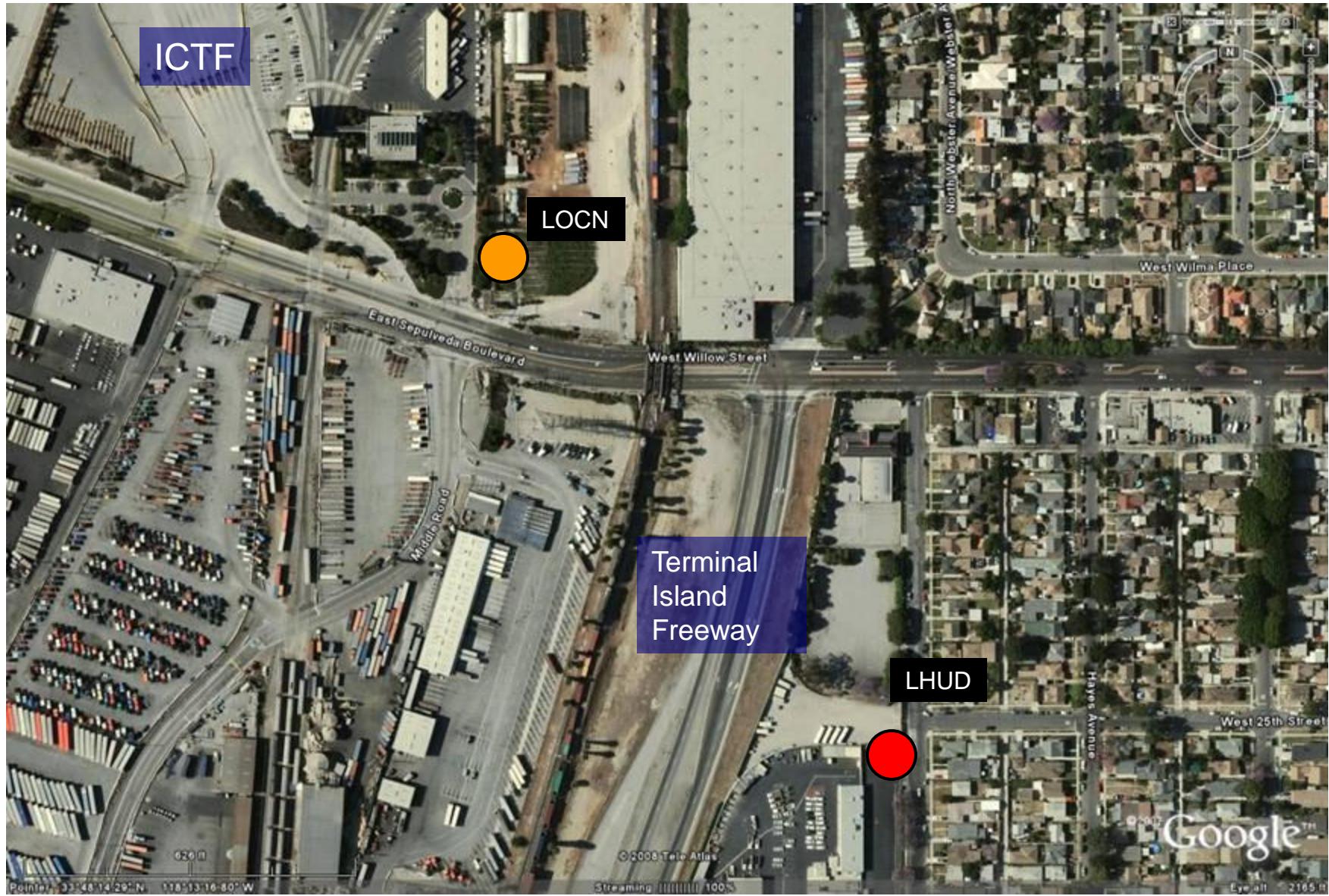
# Harbor Communities Monitoring Study (HCMS)



# Locations of HCMS Sites on Spatial Mapping of ARB's Modeling Estimate of Annual Average DPM Concentrations



# HCMS Sites Near the ICTF & Terminal Island Fwy



# Terminal Island Freeway near the Intermodal Container Transfer Facility (ICTF)



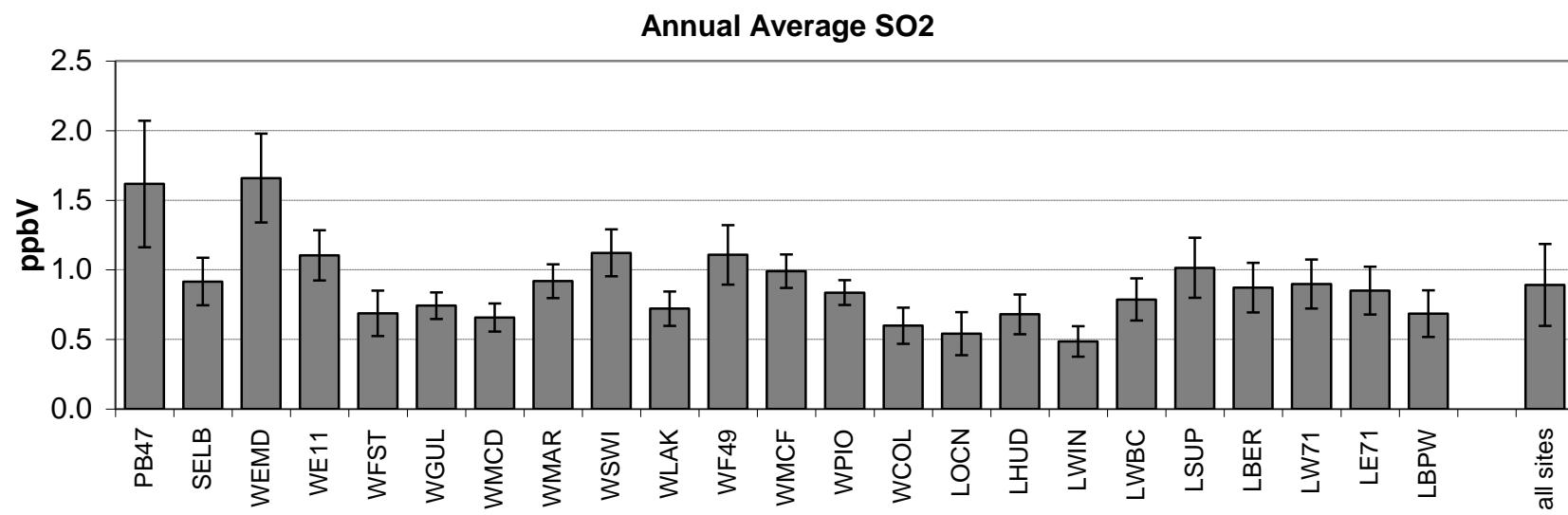
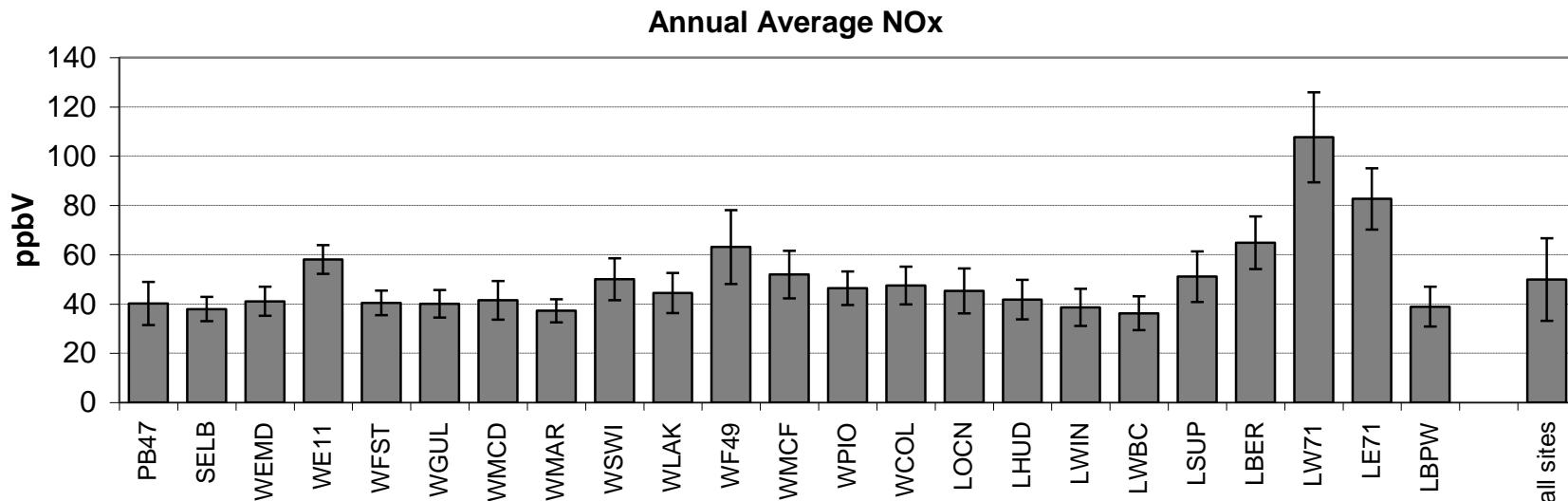
# HCMS Sites Near I-710

Pacific Coast Hwy

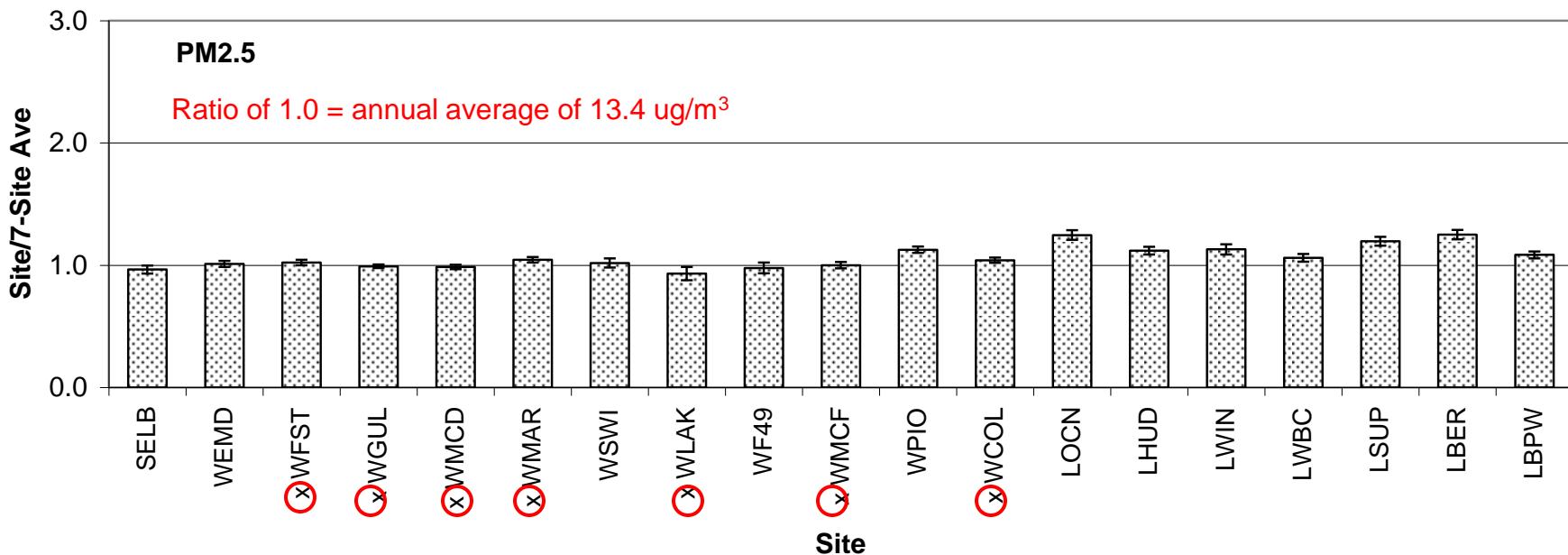
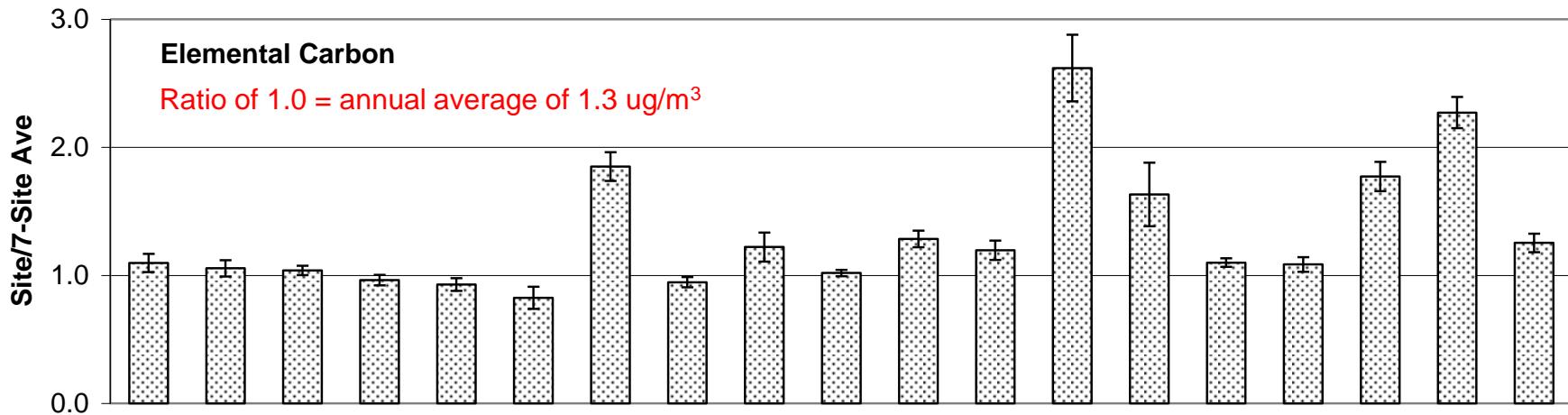


Anaheim Street

# 2007 HCMS Annual Average NOx and SO<sub>2</sub>

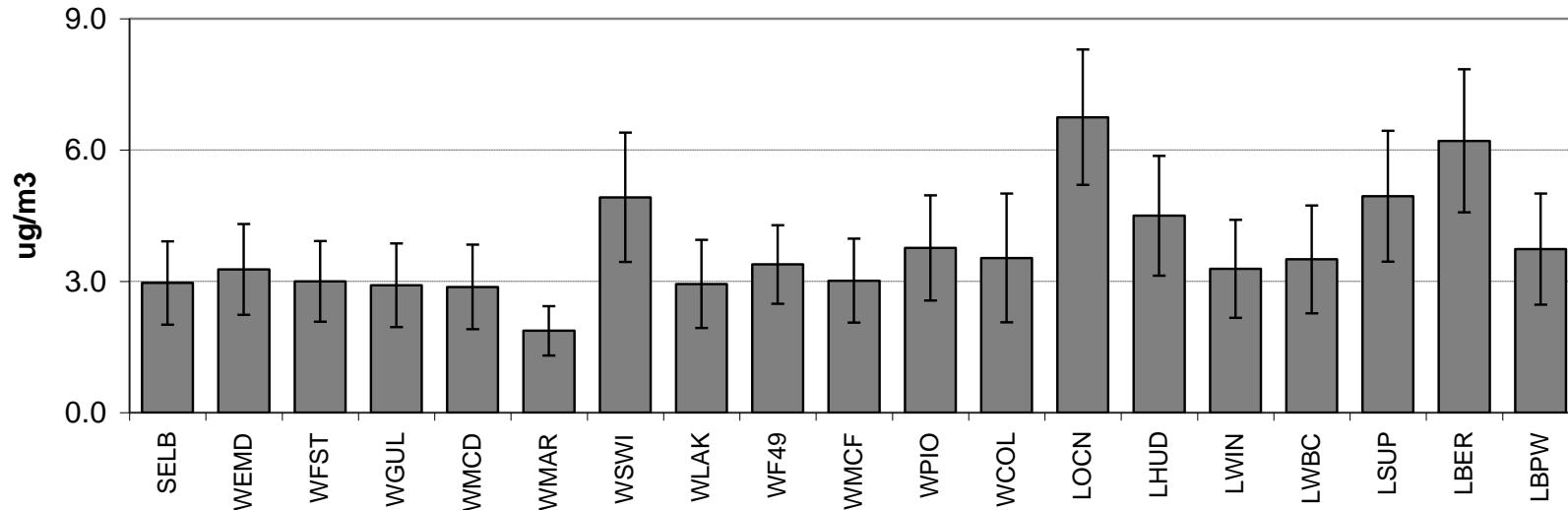


# Mean $\pm$ SE of Ratios of EC and PM2.5 to 7-Site Means

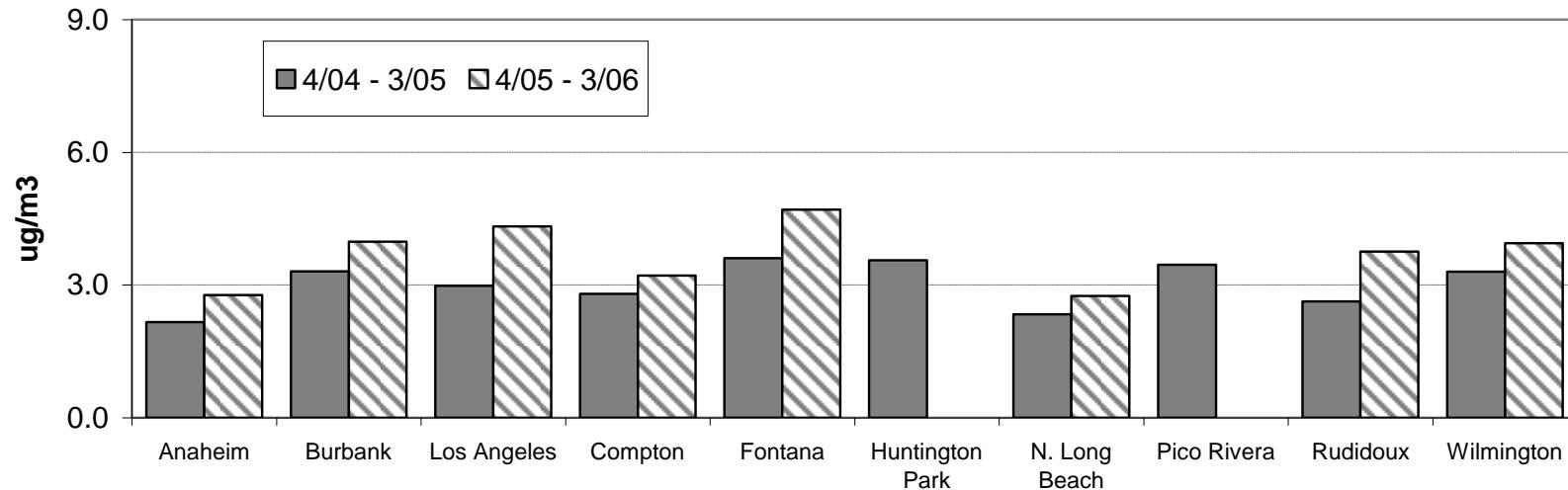


# Annual Average Diesel PM Concentrations

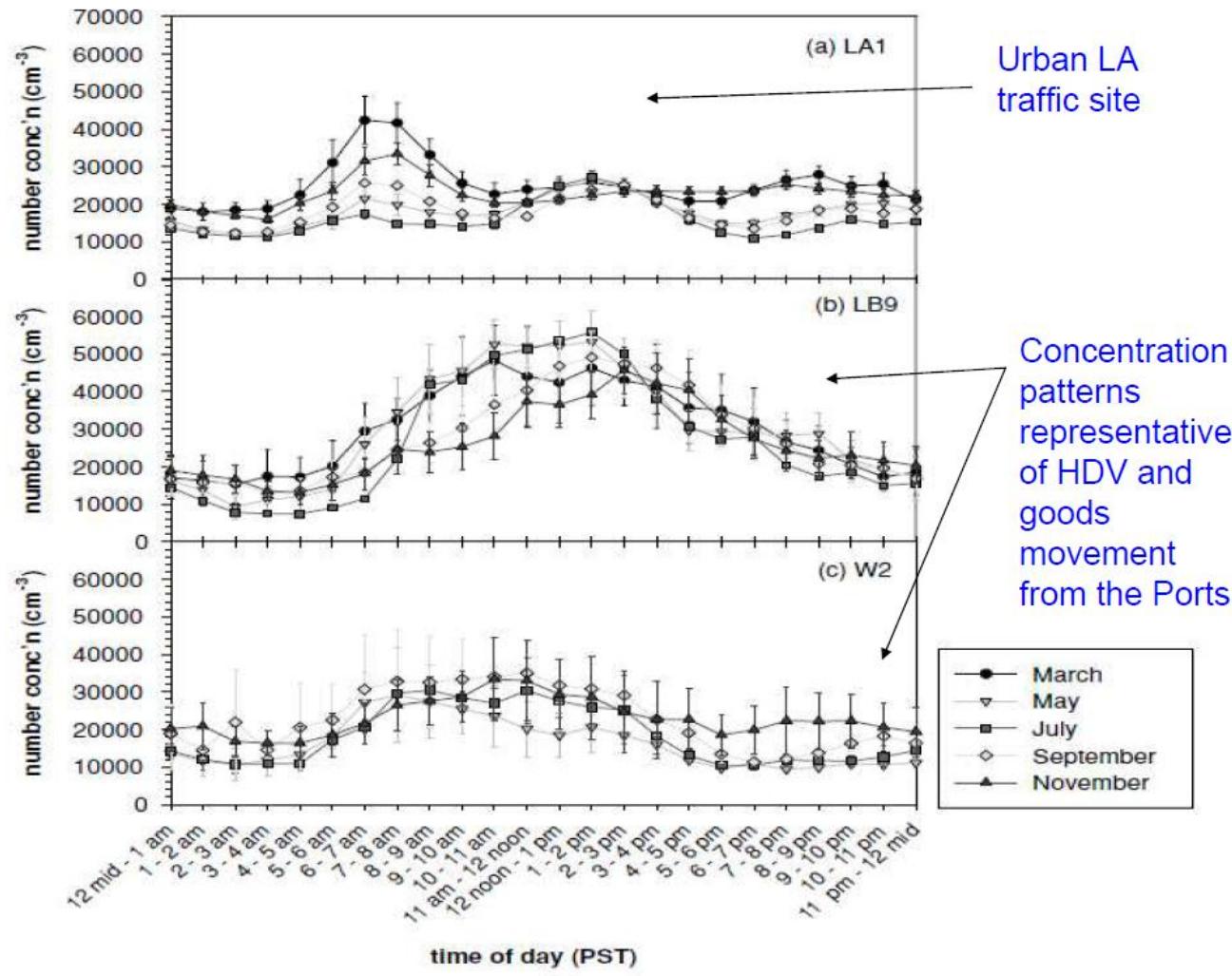
2007 HCMS Estimated DPM using EC Surrogate Method



2004-2006 MATES-III DPM from Chemical Mass Balance



# Particle Number Concentrations by CPC during HCMS



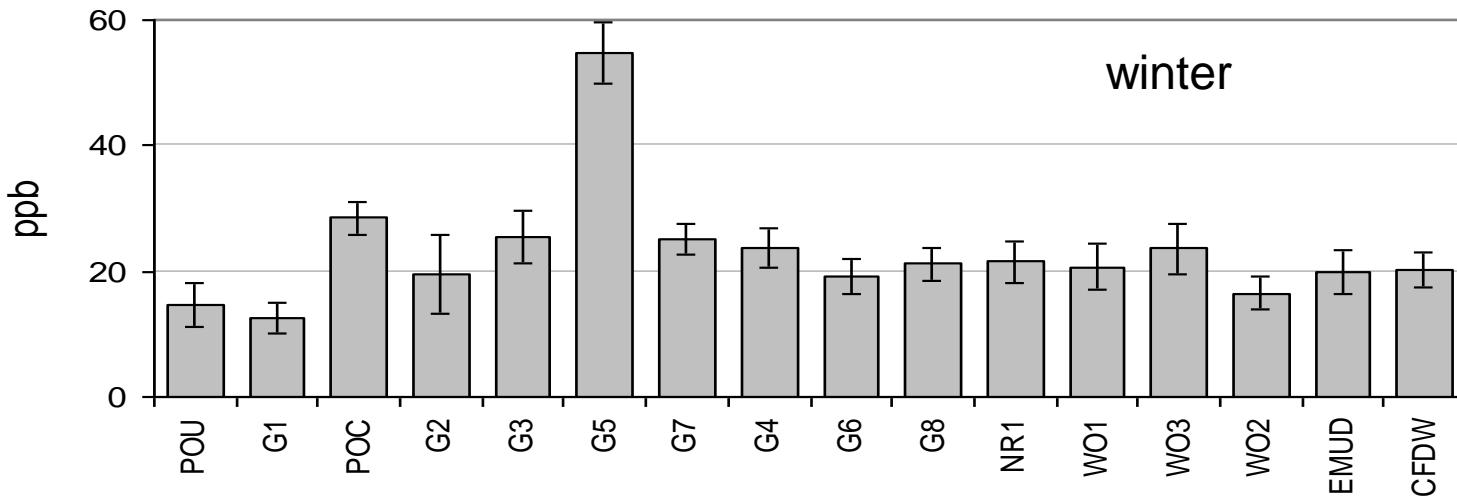
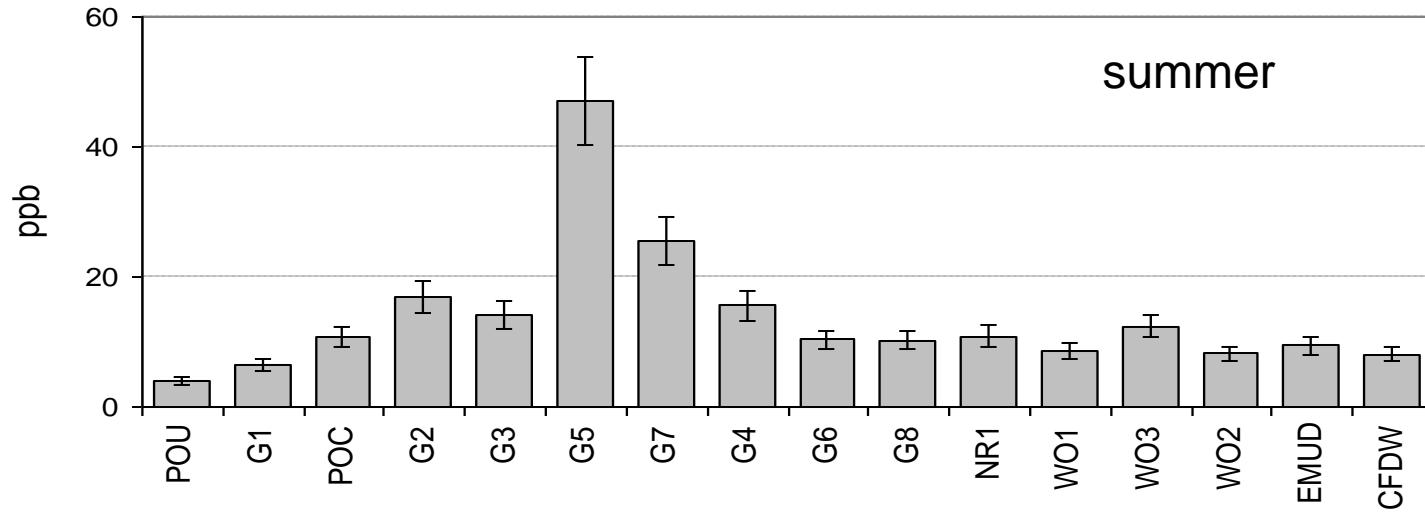
- **LA1** - USC Campus
- **LB9** - Near ICTF and end of Terminal is. Fwy.
- **W2** – Near truck route at north end of Port

Source: Sioutas, C. CARB Research Seminar, Sacramento, CA, April 26, 2010.

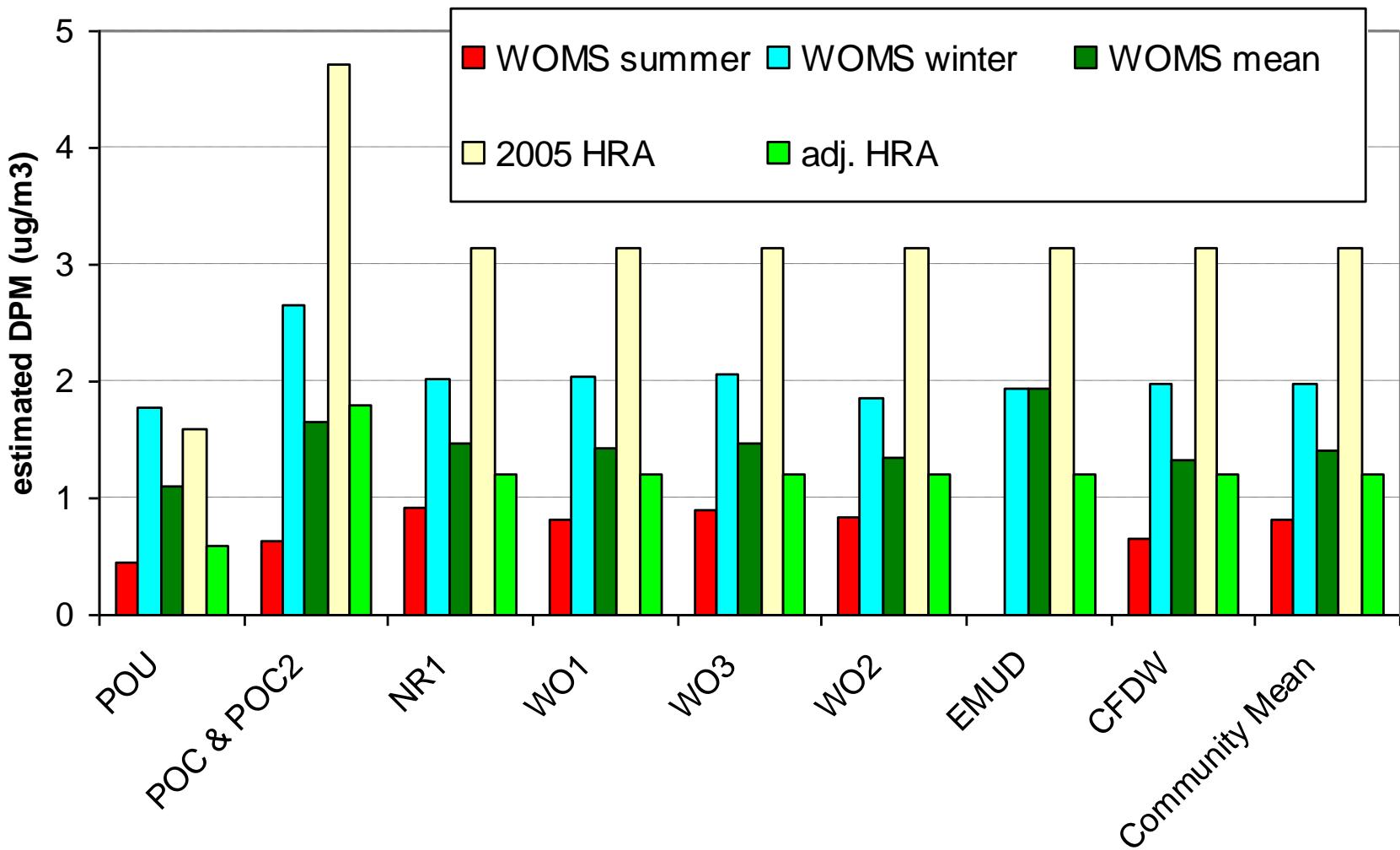
# West Oakland Monitoring Study (WOMS)



# Seasonal Average NO Concentrations



# Comparisons of DPM estimated from the WOMS saturation monitoring data with modeled results from the CARB/BAAQMD health risk assessment



# Mobile Monitoring Platforms



BAAQMD Monitoring Van



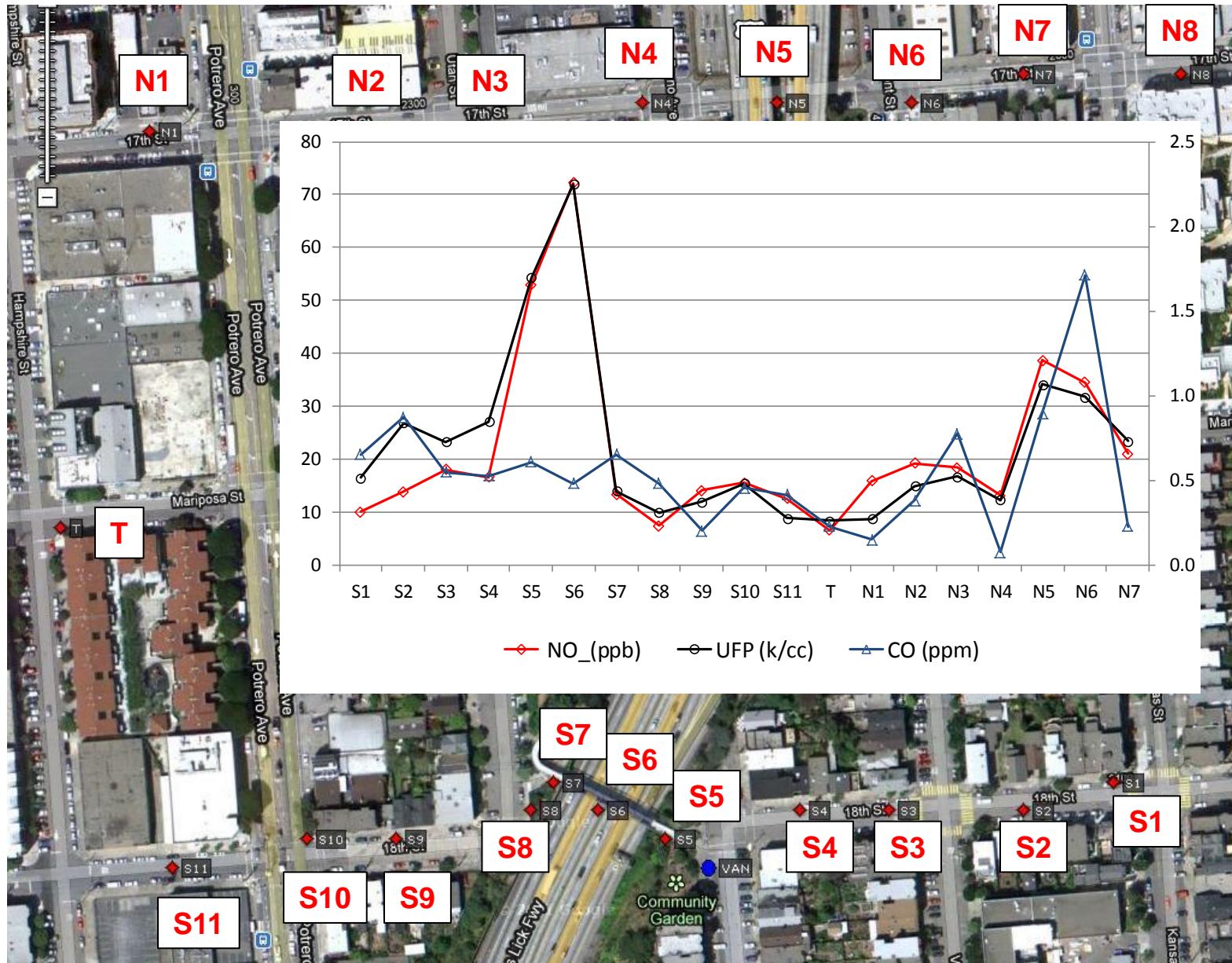
DRI Cart-Mounted  
Monitoring System

# Roadside Pollutant Gradients – US Hwy 101 (Bayshore Freeway) San Francisco

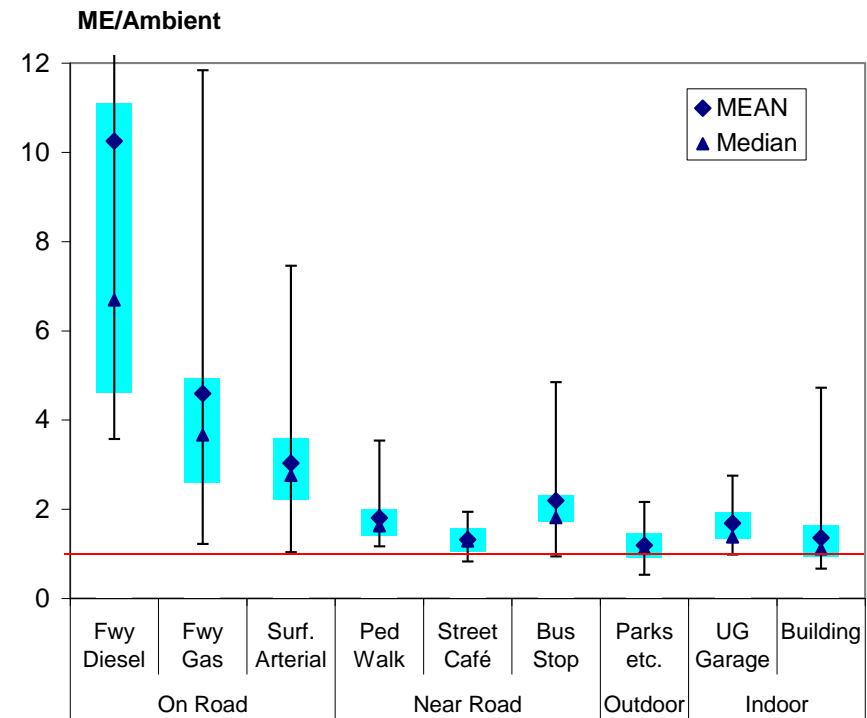
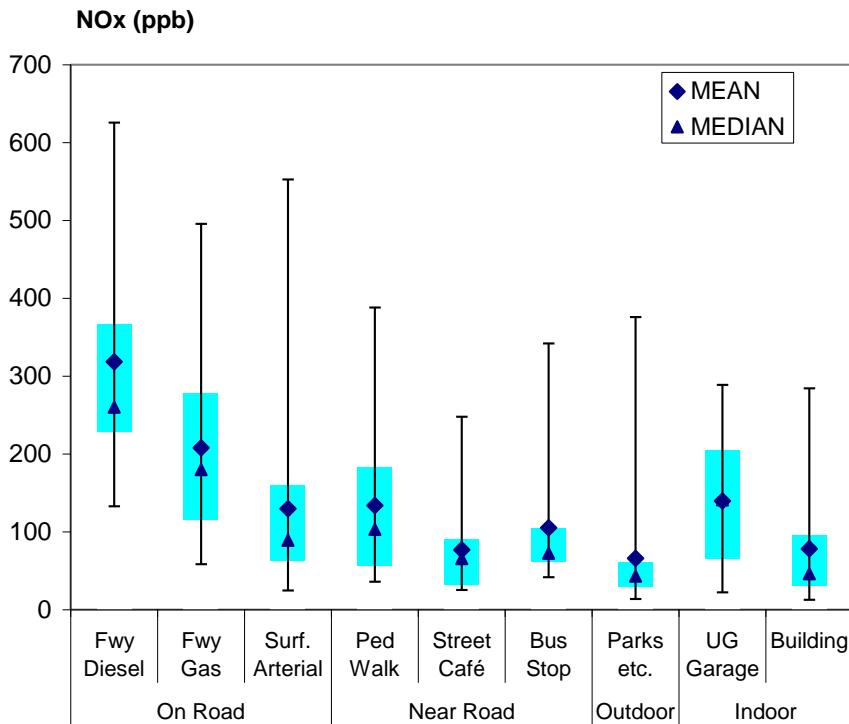
April 20, 21 and 22, 2011 at ~ 0800 to 1100 AM (5-minute ave at each site)



# Roadside Pollutant Gradients – US Hwy 101 (Bayshore Fwy) San Francisco



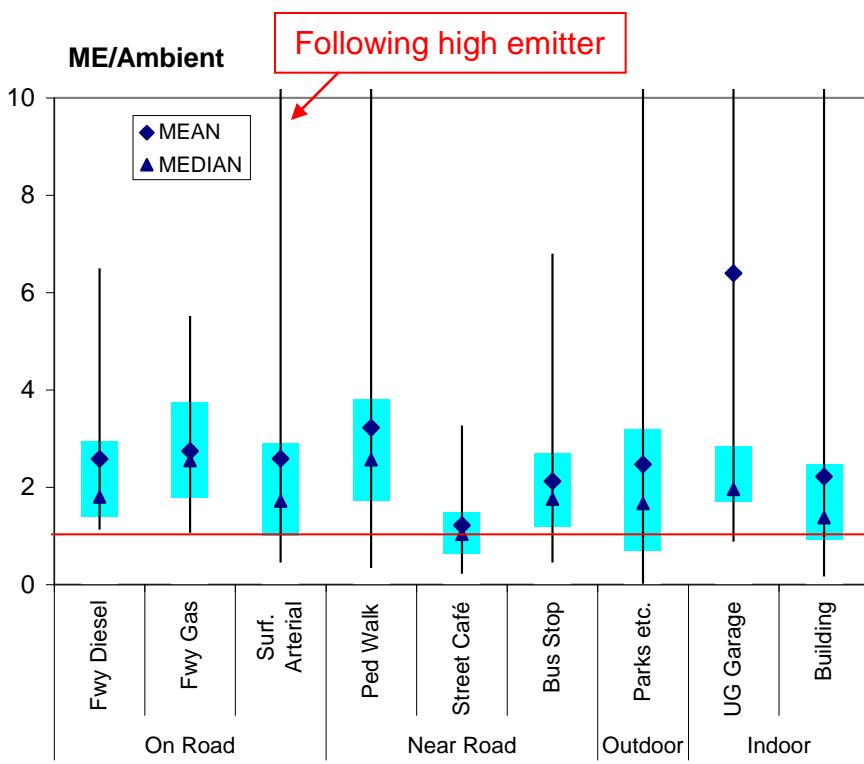
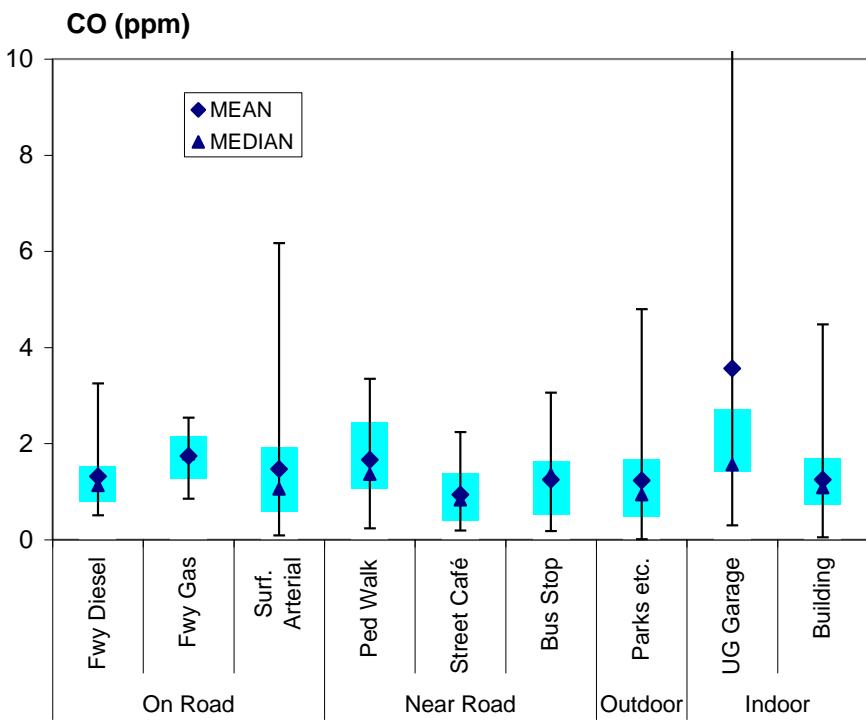
# Microenvironment NOx and ME/Ambient Ratios On-Road, Near-Road, Outdoor and Indoor MEs



Blue columns show 25-75 percentile.

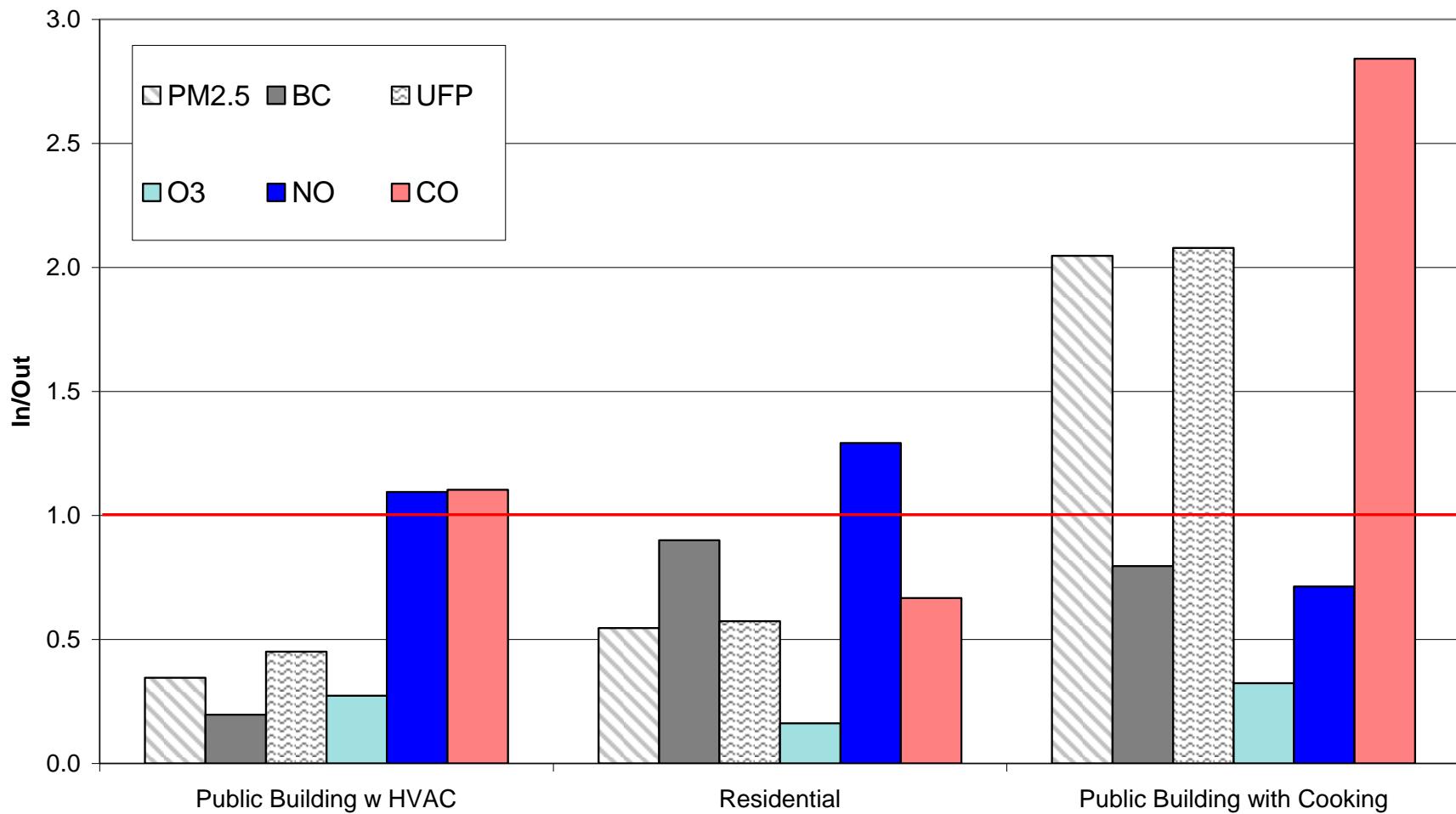
Bars show max and min.

# Microenvironment CO and ME/Ambient Ratios On-Road, Near-Road, Outdoor and Indoor MEs



Blue columns show 25-75 percentile.  
Bars show max and min.

# Indoor/Outdoor Ratios

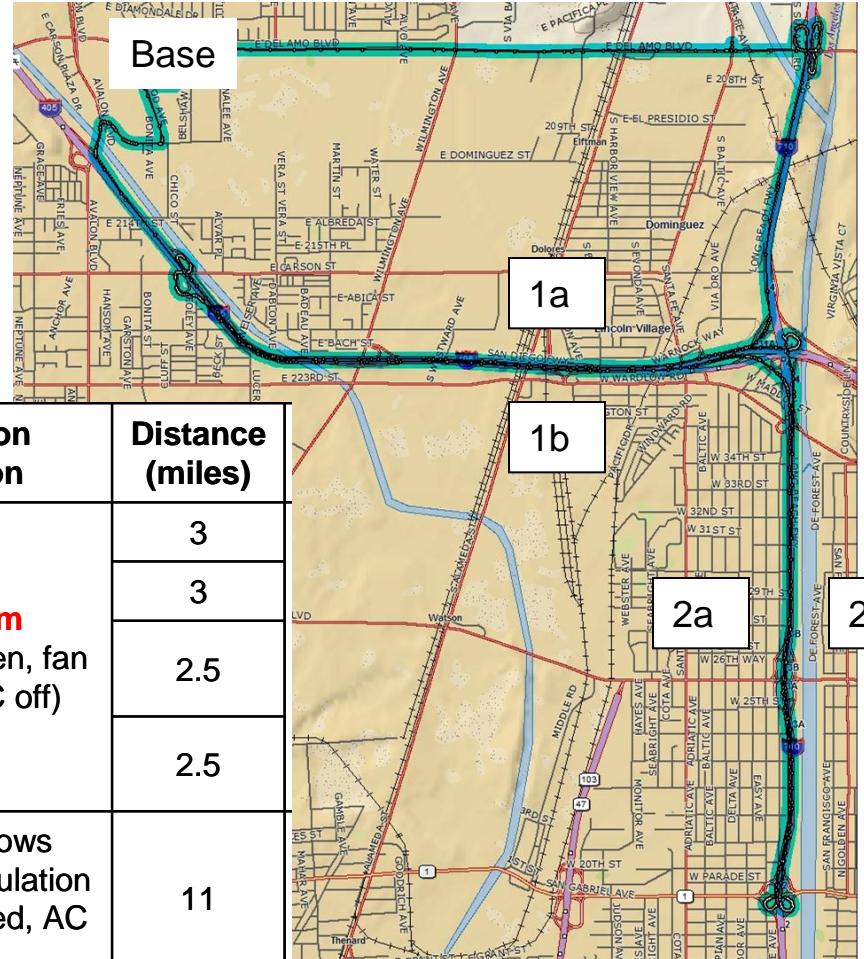


# Vehicle Ventilation Experiment

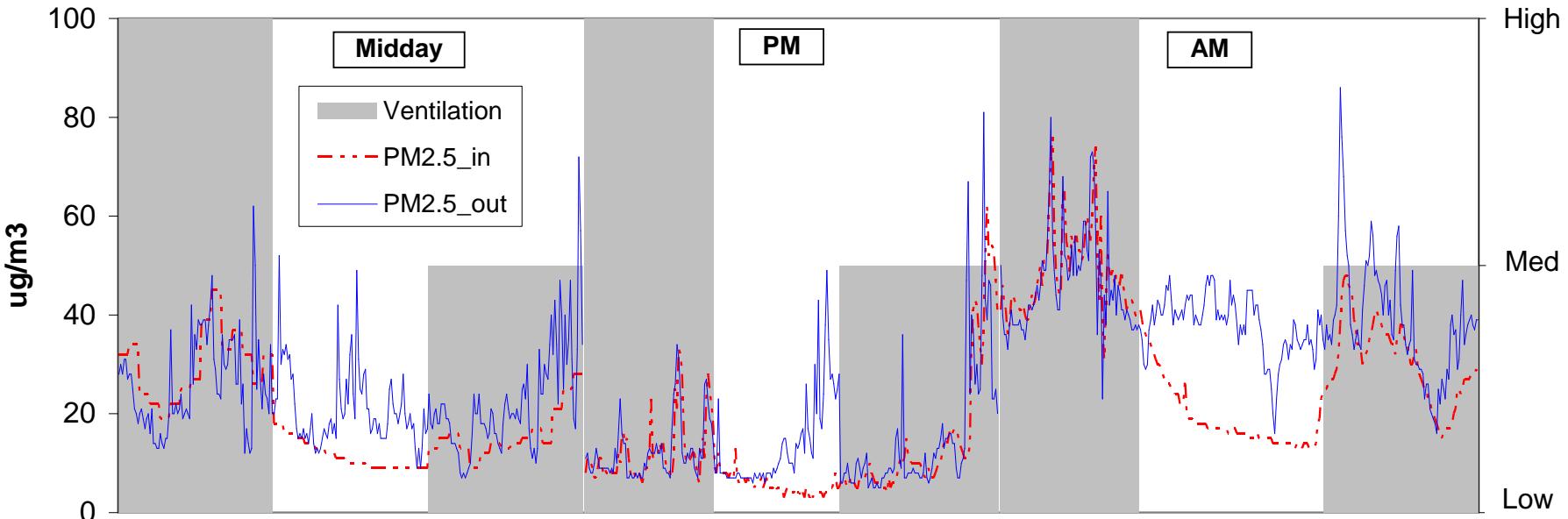
Times: Morning commute, midday, and evening commute.

Vehicles: 1996 Dodge Caravan, 2008 Nissan Altima Sedan, 2008 Cadillac SRX SUV

Location/Route	Ventilation Condition	Distance (miles)
<b>1a.</b> Northbound I-405 @ I-710 to Carson Ave.	<b>Maximum</b> (windows open, fan on med, AC off)	3
<b>1b.</b> Southbound I-405 @ Carson Ave. to I-710.		3
<b>2a.</b> Southbound I-710 @ I-405 to Pacific Coast Highway or Anaheim St. depending on traffic.		2.5
<b>2b.</b> Northbound I-710 @ PCH or Anaheim St. to I-405 Interchange		2.5
Repeat Route 1a, 1b, 2a, and 2b	<b>Low</b> (windows closed, recirculation on, fan on med, AC on)	11
Repeat Route 1a, 1b, 2a, and 2b	<b>Med</b> (windows closed, recirculation off, fan on med, AC off)	11

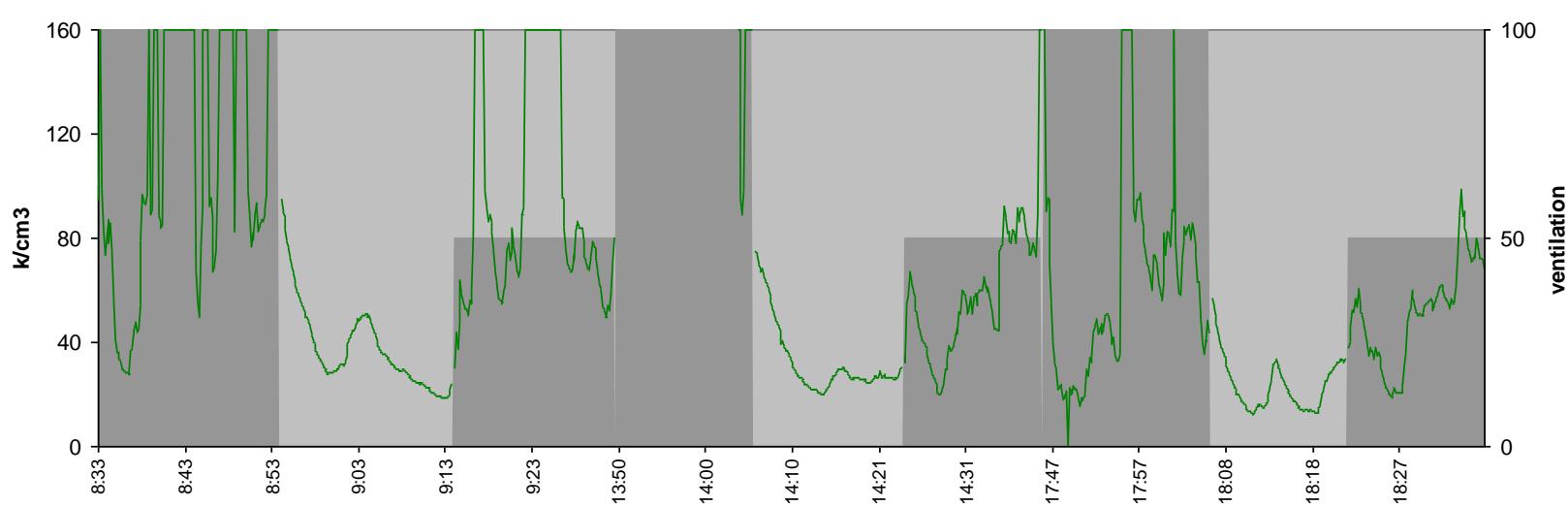
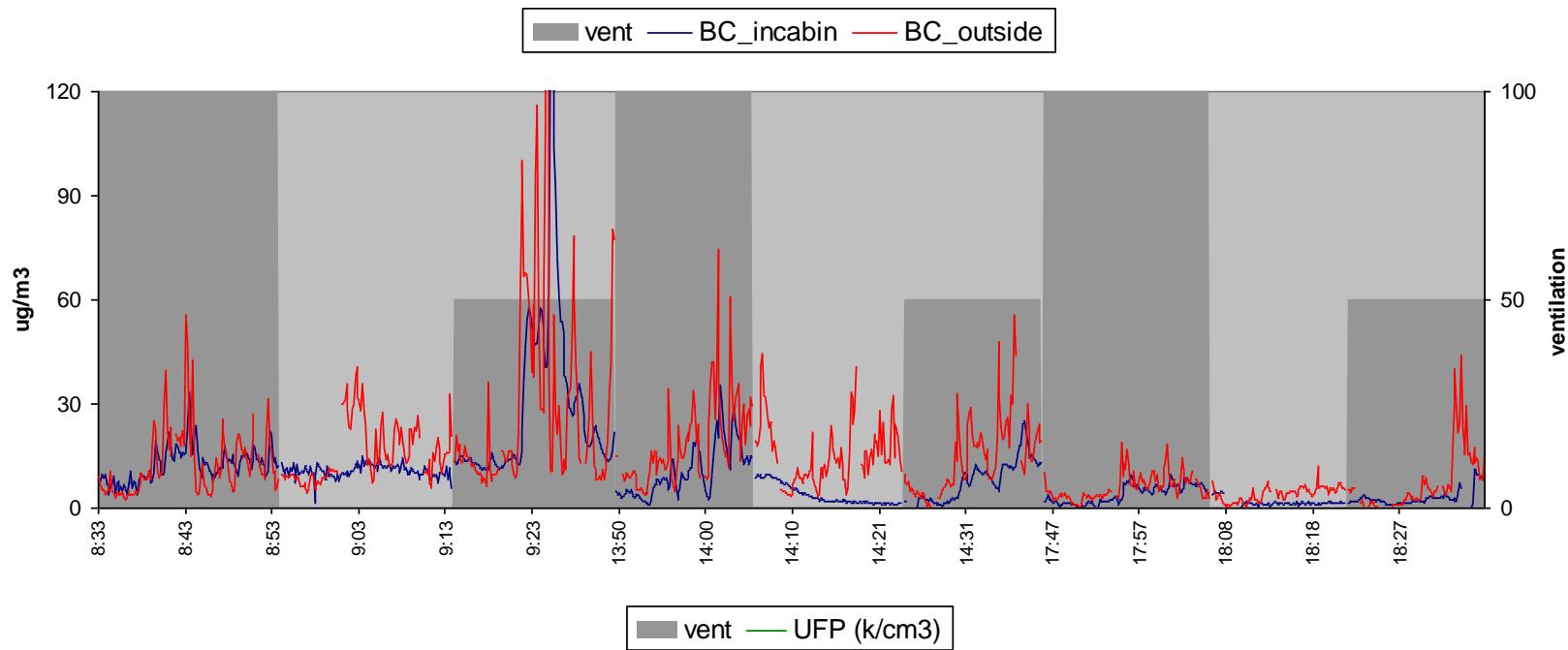


# Vehicle Ventilation Expt, 2008 Cadillac SRX

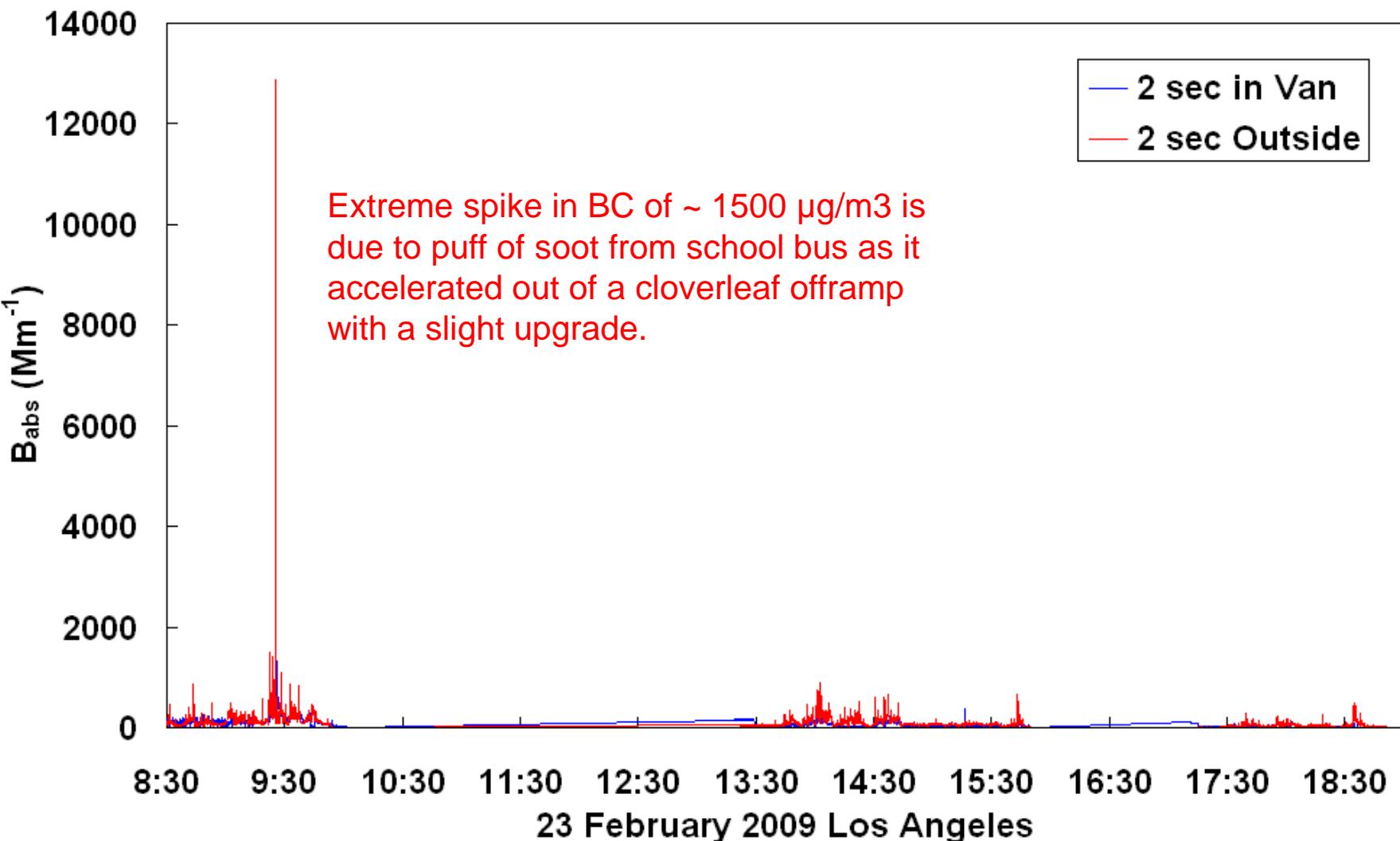


Sampling Inlet System for  
In-Vehicle Ventilation Experiment

# Vehicle Ventilation Expt, 1996 Caravan – 2/23/09

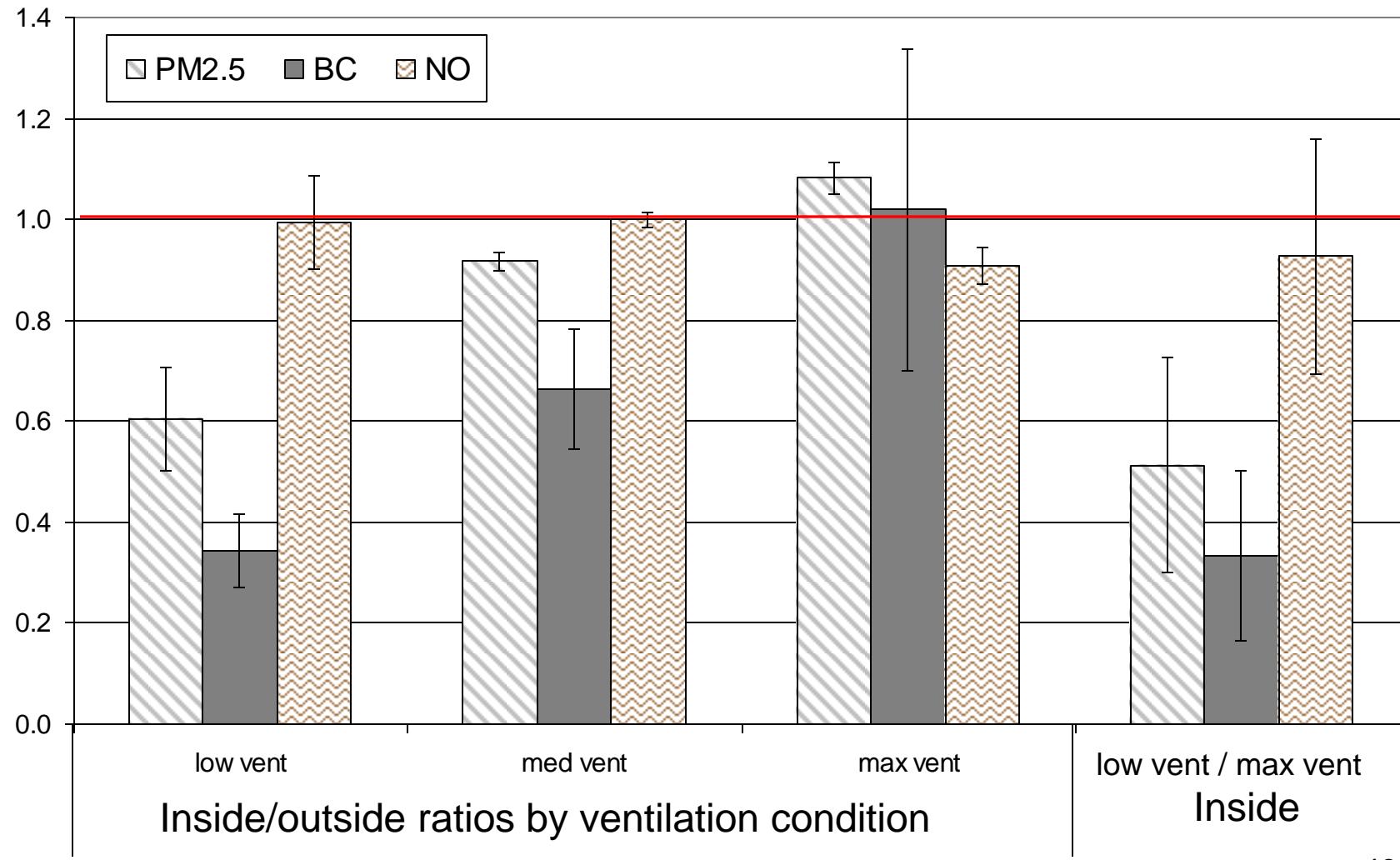


# Black Carbon Mass Concentration

$$(\text{ug m}^{-3}) = \text{B}_{\text{abs}} (\text{Mm}^{-1}) / 8.8$$


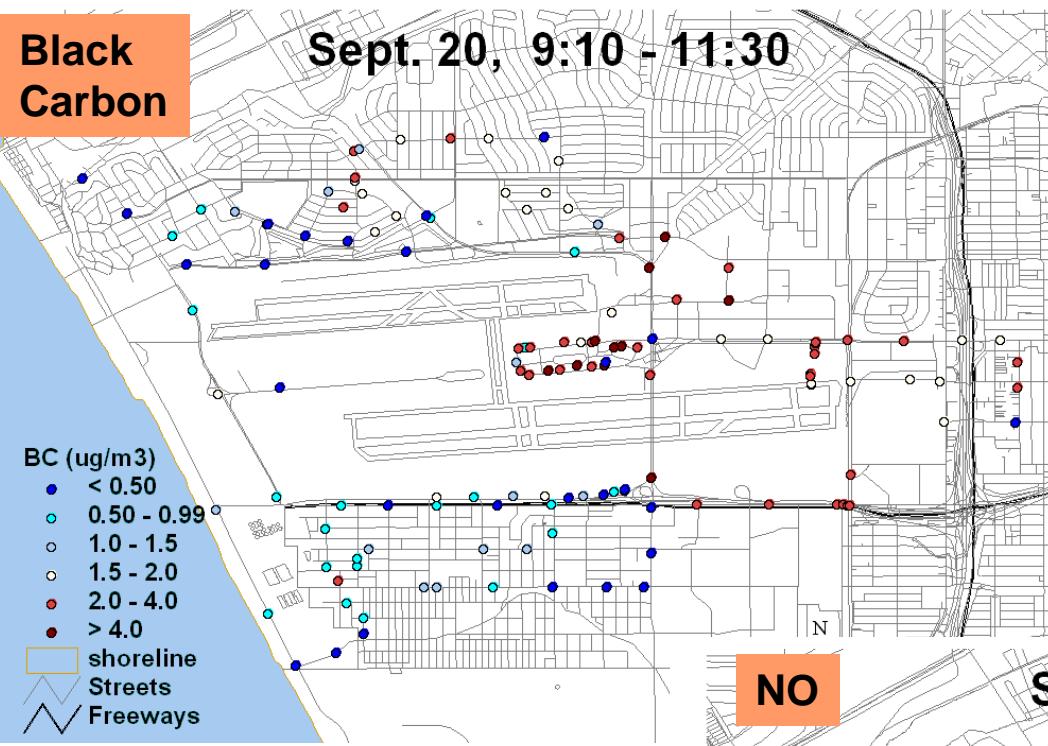
# Effect of Ventilation Condition on In-Vehicle Pollutant Concentrations

in/out or low/max ratios



**Black  
Carbon**

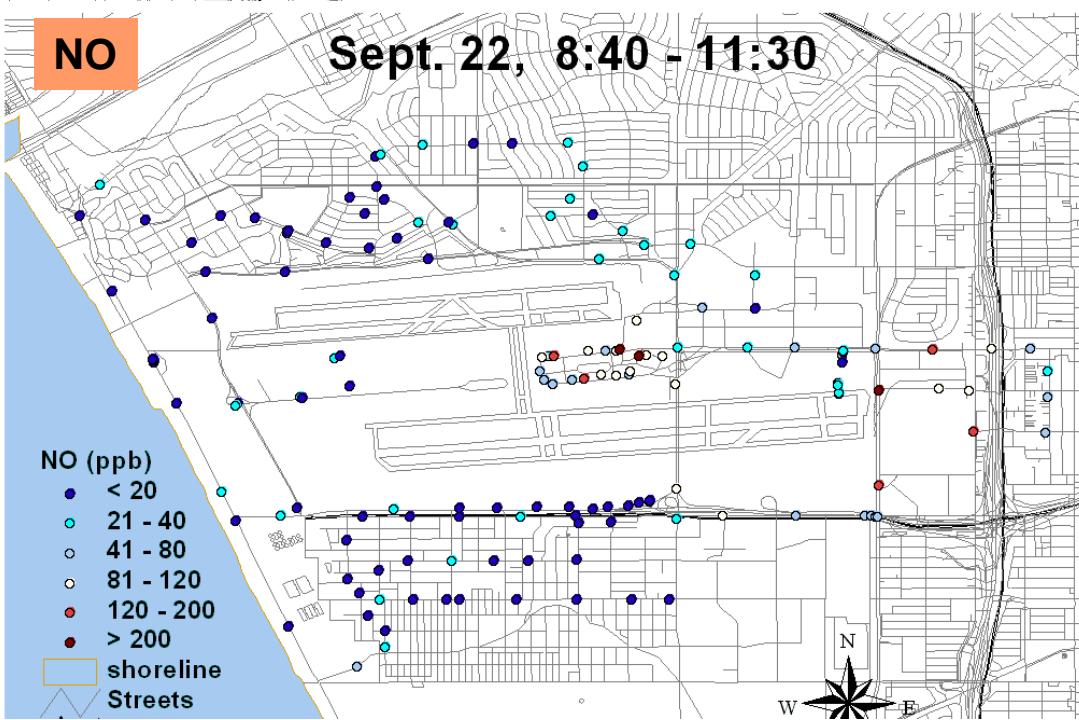
**Sept. 20, 9:10 - 11:30**



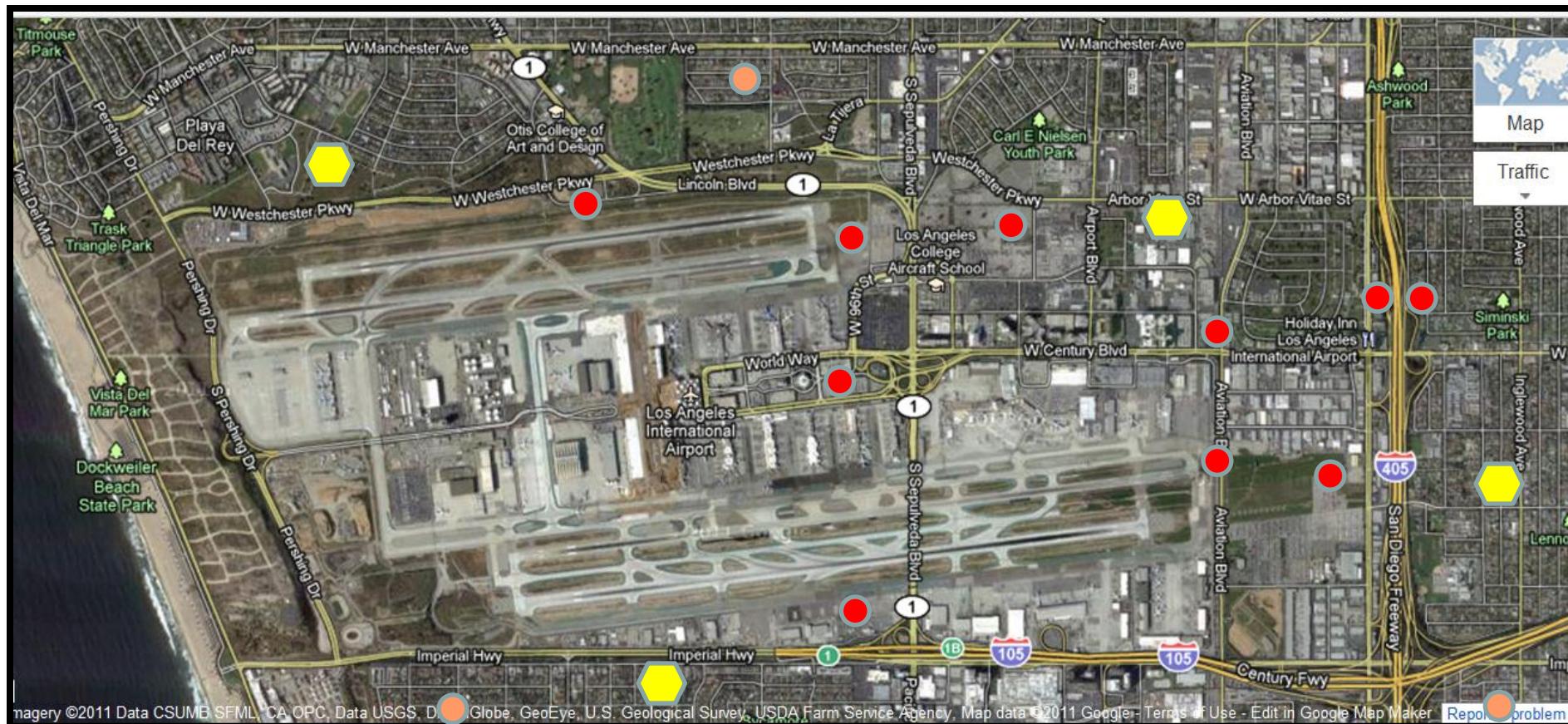
**Phase 3 LAX AQSAS  
Spatial Survey of BC and NO**

**NO**

**Sept. 22, 8:40 - 11:30**



# Phase 3 LAX AQSAS Monitoring Sites



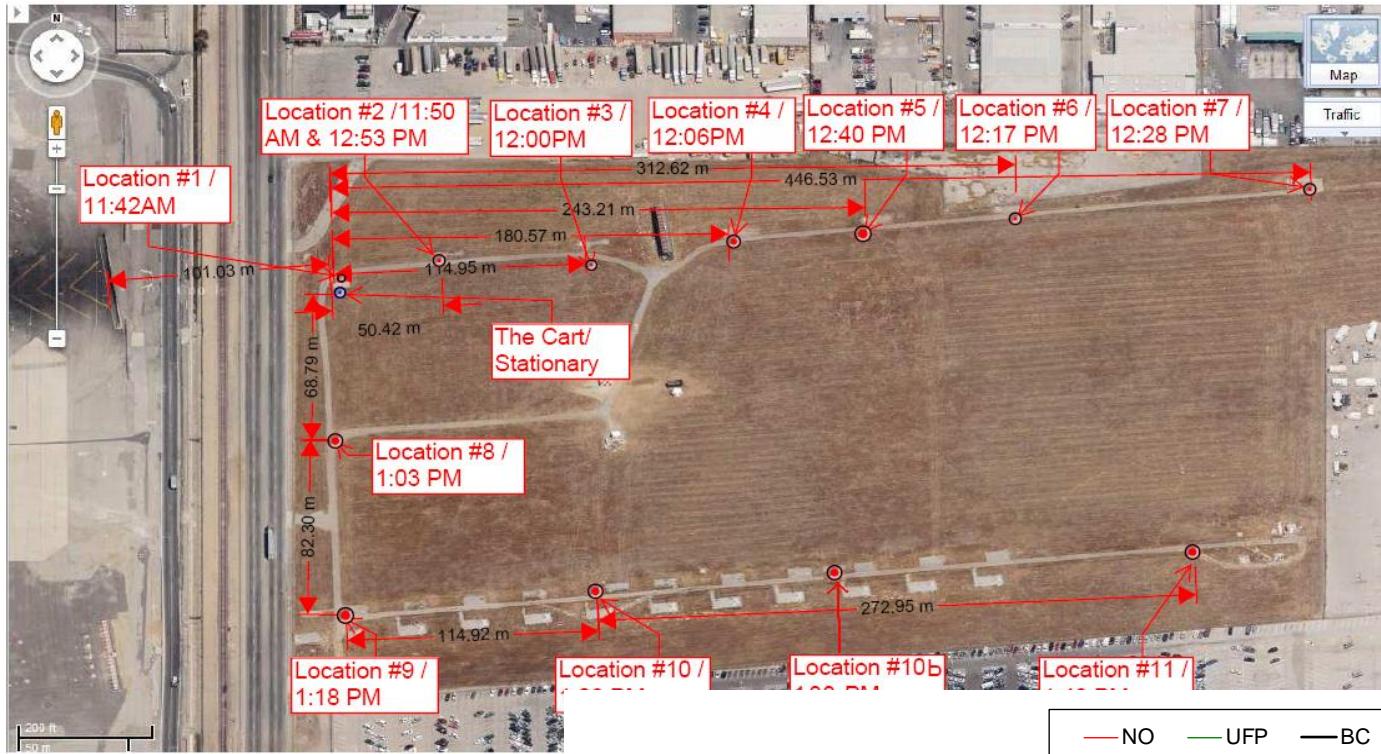
Baseline Monitoring Sites (continuous, speciation sampling, mini-vol, passive gas)



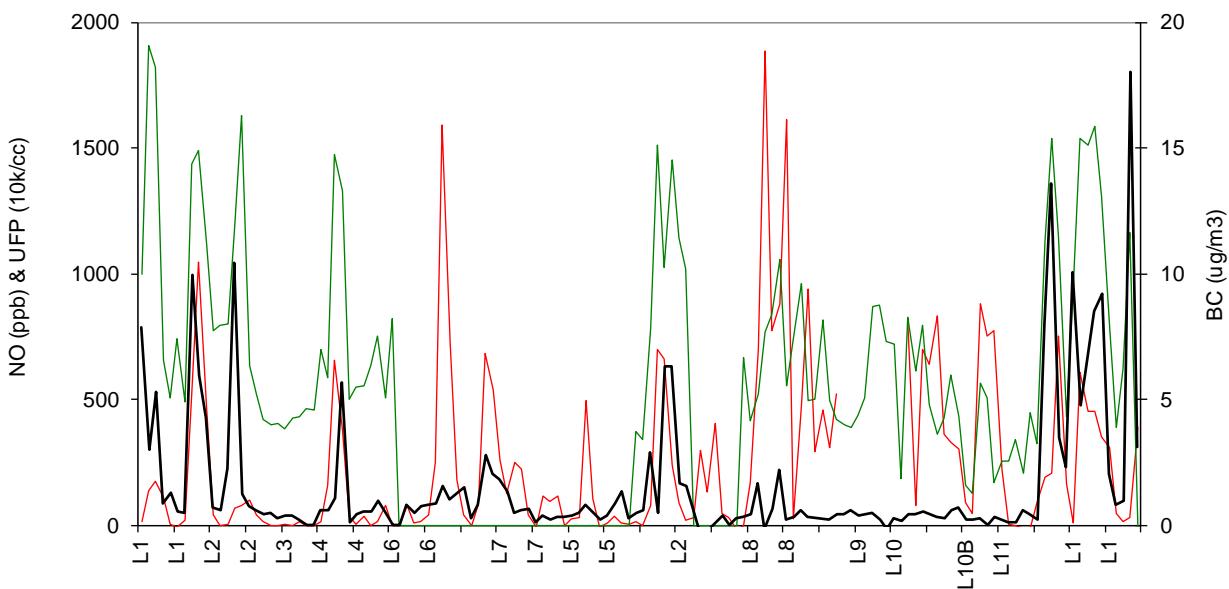
Mini-volume aerosol and passive gas samplers at Baseline & Satellite Sites



Passive gas samplers only at Gradient Sites



## Phase 3 LAX AQSAS Pollutant Gradients Downwind of Runway 25R

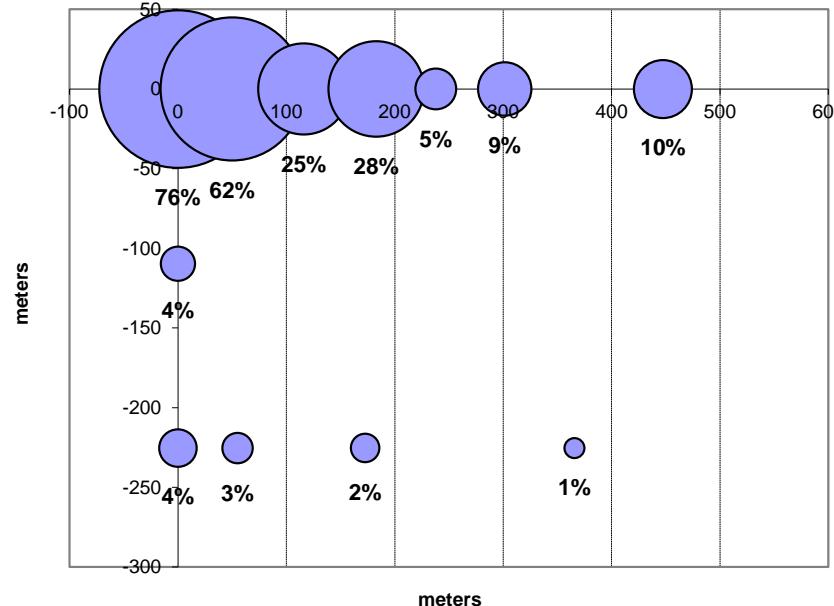




NO Concentrations Relative to Reference Site

## Phase 3 LAX AQSAS Pollutant Gradients Downwind of Runway 25R

LAX AQSAS



# Summary

- On-road and roadside pollutant concentrations.
  - ~ 5 to 10 times higher near diesel exhaust (NOx, black carbon, UFP).
  - ~ 2 to 4 times higher near gasoline exhaust (CO, VOC including BTEX).
  - Steep gradients - near community background ~ 300 m from source.
  - In-vehicle ~ 1/3 of on-road concentrations under low ventilation conditions
  - Avoid following diesel truck and gasoline smokers.
  - 2007 diesel standards will result in substantial reduction in PM emissions (e.g., already noticeable reduction at CA Ports)
- Other urban microenvironments.
  - HVAC systems are effective in reducing ambient PM.
  - PM higher in public building with cooking (e.g., food courts)
  - Wood combustion.